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# QUARTERLY PROGRESS REPORT NO. 2
# SEGMENTED ROCKET MOTOR CASE PROGRAM

29 OCTOBER 1962

DOUGLAS REPORT SM-42516

MISSILE & SPACE SYSTEMS DIVISION
DOUGLAS AIRCRAFT COMPANY, INC.
SANTA MONICA CALIFORNIA

DOUGLAS

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MISSILE SYSTEMS ENGINEERING | MISSILE & SPACE SYSTEMS DIVISION
DOUGLAS AIRCRAFT COMPANY, INC.

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# FOREWORD

This is the second quarterly report on the work performed by Douglas Aircraft Company under USAF Contract AF 04(611)-8184 during the interim from 15 July 1962 to 15 October 1962. The contract is a 13-month research and development program directed toward design, development, fabrication, and testing of lightweight motor case segments, culminating in a design applicable to large segmented solid propellant rocket motors.

## ABSTRACT

This is an interim report on a research and development program directed toward design, development, fabrication, and testing of lightweight motor case segments, culminating in a design applicable to large (160- to 240-in. dia.) segmented solid propellant rocket motors.

A summary of work accomplished on the bench test program and on the 43-in. dia. subscale segments is included. Completed tests are described in detail. A computer program developed for the determination of stresses in lap joints and a revised strength analysis (originally presented in Quarterly Progress Report No. 1) are included in the Appendices.

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## 1.0 INTRODUCTION

### 1.1 Summary of Program Scope and Approach

This document is the second quarterly progress report for Contract No. AF 04(611)-8184 sponsored by Rocket Research Laboratories, Edwards, California. The objective of this contract is to conduct a comprehensive program for the design, analysis, development, fabrication, and testing of a complete 43-in. dia. subscale solid propellant rocket motor segment. An optimum segment design will be determined which will incorporate minimum weight, high reliability, easy segment assembly and disassembly, and low over-all cost. In addition, the feasibility of scaling the subscale 43-in. dia. segment to full size 160 and 240-in. diameters will be determined. Propellant and aerodynamic heating, flight and ground handling loads, and fabrication techniques expected for the full-size segments will be considered.

### 1.2 Summary of Progress Reported in Quarterly Progress Report No. 1

The first Quarterly Report included discussions of the basic motor case segment design concept, of the design of a 43-in. dia. subscale motor case segment, and of the test programs being conducted to implement segment design. Work accomplished on the 43-in. dia. segments and on the test program was summarized, and completed tests were described in detail. Drawings of the 43-in. dia. segment and its proof test assembly were included. Analytical techniques developed to assist in segment design and a strength analysis of the 43-in. dia. segment were presented in the Appendices.

### 1.3 Summary of Work Accomplished from 15 July 1962 to 15 October 1962

All work is progressing on schedule, except as noted below, and has been accomplished within the originally established budget with approximately 48% of the total program budget having been expended as of 15 October 1962.

A brief summary of work accomplished during the current report period follows. The topics listed are presented in greater detail in the Discussion (Section 2.0).

a. <u>Development of Computer Program</u>

A computer program has been developed for the determination of shear and direct stresses in a lap joint. (See Discussion and Appendix A.)

b. <u>Revision of Strength Analysis</u>

The strength analysis presented in Appendix A of Quarterly Progress Report No. 1 has been revised. (See Discussion and Appendix B.)

c. <u>Non-Scheduled Testing</u>

Fifty NOL (Naval Ordnance Laboratory) rings and eight cloth laminate flexural test specimens have been tested to assist final selection of a resin-glass system.

d. <u>Development of Pre-Preg Tape</u>

A fiberglas tape-making machine is now operational and is being used to develop pre-impregnated fiberglas tape for the construction of bench test specimens and 43-in. dia. segments.

e. <u>Status of Bench Test Program</u>

Testing of the six 6-in. dia. by 18-in. long segmented joint bench test specimens is approximately eight weeks behind schedule. This delay is primarily because of a decision to fabricate and test the specimens one at a time so that any modifications indicated by test results can be integrated into the design and fabrication of subsequent specimens.

Fabrication of the 16-in. dia. by 12-in. long compression test cylinders is approximately 2 weeks behind schedule, but this lag will not affect fabrication and testing of other items.

Two 3-in dia. by 9-in. long burst test cylinders have been tested in addition to the twelve cylinders reported in Quarterly Progress Report No. 1. Ten 4-in. dia. by 9-in. long interlaminar shear tension test specimens and six 4. in. dia. by 4-1/2-in. long interlaminar shear, metal-to-glass, compression test specimens have been tested. Also, a clamp pull test, and one 6-in. dia. by 18-in. long segmented joint test specimen have been tested.

f. Status of 43-In. Dia. Segments

Tooling and detail parts for fabrication of the 43-in. dia. segments are being constructed and two of the 43-in. dia. test closures are completed. Fabrication of the first 43-in. dia. segment is behind schedule approximately four weeks due to difficulty which was encountered in completing the tooling. This situation has been corrected, however, and no further delays are expected.

## 2.0 DISCUSSION

A discussion of work accomplished during the current report period follows. A general discussion of the 43-in. dia. subscale segments and the bench test program was included in Quarterly Progress Report No. 1 and will not be repeated in this report.

### 2.1 Development of Computer Program

A 7090 Computer Program, F449, has been developed for the determination of shear and direct stresses in lap joints. The analytical techniques presented in Appendices B, C, and F of Quarterly Progress Report No. 1 can be used to predict stresses in lap joints. However, the techniques are valid only for lap joints of constant thickness and for lap joints which taper to zero thickness. The techniques can be used, however, to estimate the dimensions for a particular lap joint. These dimensions can then be used as inputs to the computer program from which exact values of stresses will be obtained.

### 2.2 Revision of Appendix A of Quarterly Progress Report No. 1

The expression for Z given in Appendix A (Strength Analysis) of Quarterly Progress Report No. 1 is incorrect. The strength analysis has been corrected and appears in Appendix B of this report. The values of Z obtained using the corrected expression for Z were larger than the original values. Therefore, since stress decreases as Z increases, higher Margins of Safety were obtained. The minimum Margin of Safety for the joint composite section given in the Strength Analysis of Report No. 1 was -.018 while the minimum value is zero in the corrected analysis.

## 2.3 Non-Scheduled Testing

In addition to scheduled bench testing (see Section 2.5 below) several contributary tests have been conducted to assist final selection of a resin-glass system for the construction of the 43-in. dia. subscale segments. A description of these tests follows:

### 2.3.1 NOL Ring Tests

Twenty NOL rings were tested to evaluate the effect of different cure cycles on strength values. The results of the tests are shown in Table 1 and indicate that cure cycle No. 1 (2 hours at 200°F and 4 hours at 250°F) gives the highest tensile strengths. The resin is not completely cured with cure cycle No. 1 and therefore has a higher elongation than it would have if completely cured. This increased elongation may have caused the higher tensile strengths. Thirty additional NOL rings were tested to evaluate various resin systems. The results of the tests are shown in Table 2 and show that Epon 828/CL and ERLA 2256/ZZL0820 resin systems give the highest tensile strengths. Each of the five resin systems evaluated were fully cured as indicated in the table of test results.

All 50 NOL rings were 2-5/8 inch I.D. and were prepared per MRD-1P20019 (Materials Requirement Drawing) using 360 turns of single end HTS glass.

### 2.3.2 Flexural Tests

Eight 1/8-inch by 1-inch by 4-inch No. 143 cloth laminates were flexural tested to determine flexural strengths and moduli of fiberglas as a function of cure cycle. The specimens were prepared and tested per Douglas

TABLE 1

NOL Ring Tests (For Resin System Evaluation)

| Cure Cycle | Material | | No. Specimens | Avg. Ultimate Glass Stress (psi) |
|---|---|---|---|---|
| | Glass | Resin | | |
| #1 2 hours at 200°F, 4 hours at 250°F | HTS Single End | 2638.6/MNA/BDMA | 5 | 282,000 |
| #2 4 hours at 120°F, 2 hours at 180°F, 2 hours at 250°F | HTS Single End | 2638.6/MNA/BDMA | 5 | 264,000 |
| #3 2 hours at 200°F, 6 hours at 350°F | HTS Single End | 2638.6/MNA/BDMA | 5 | 270,000 |
| #4 2 hours at 200°F, 3 hours at 400°F | HTS Single End | 2638.6/MNA/BDMA | 5 | 257,000 |

TABLE 2

NOL Ring Tests (For Cure Cycle Evaluation)

| Cure Cycle | Material | | No. Specimens | Avg. Ultimate Glass Stress (psi) |
|---|---|---|---|---|
| | Glass | Resin | | |
| Jell at room temperature, 2 hours at 185°F, 4 hours at 300°F | HTS Single End | Epon 828/CL (Shell) | 6 | 284,200 |
| Jell at room temperature, 2 hours at 185°F, 4 hours at 300°F | HTS Single End | ERLA 2256/ZZL0820 (Union Carbide) | 4 | 289,600 |
| | | | 4 | 279,600 |
| Jell at room temperature, 2 hours at 185°F, 2 hours at 230°F, 3 hours at 300°F, 3 hours at 350°F | HTS Single End | ERLA 0500/MNA (Union Carbide) | 5 | 272,600 |
| 2 hours at 185°F, 4 hours at 300°F | HTS Single End | ERSA 0112/$BF_3$MEA (Union Carbide pre-preg) | 6 | 241,600 |
| 2 hours at 185°F, 2 hours at 250°F, 2 hours at 300°F | HTS Single End | Epon 1028-B70/DDS/ $BF_3$MEA (Shell Pre-Preg) | 5 | 270,000 |

DLP 13.303 (Douglas Laboratory Procedure) with results as shown in Table 3. The results indicate that higher flexural strength values are obtained with a cure of 3 hours at 180°F, 2 hours at 250°F, and 2 hours at 400°F than with a cure of 3 hours at 180°F and 2 hours at 250°F.

## 2.4 Development of Pre-Preg Tape

A Douglas-funded tape-making machine has been completed (except for correction of a few minor imperfections) and suitable tape is being produced (see Figures 1 and 2). The longitudinal plies of the bench test specimens currently under construction are being made from tape produced on this machine. The machine tape is a much better quality tape than the "interim" tape used in the first bench test specimens. Presently, the resin content of "machine" tape is varying from 13 to 22 percent. This variation is less than that of the "interim" tape. However, the variation is still too large and work is continuing to develop tape with a more constant resin content.

## 2.5 Bench Testing

Two types of bench tests have been added to the eight original types described in Quarterly Progress Report No. 1. One of these tests is a clamp pull test for determining clamp strength and the other is a wedge shear test for evaluating a new stave anchoring concept which may prove superior to the existing anchoring concept. The ten types of bench test specimens are shown in Figures 3 and 4. The testing and fabrication status of the bench test program is as follows.

### 2.5.1 3-In. Dia. by 9-in. Long Burst Test Cylinders

Two 3-in. dia. by 9-in. long burst test cylinders (1A35798-501)

TABLE 3

Flexural Test Specimens (Four Specimens For Each Cure)

| Cure Cycle | Material | | Composite Flexural Strength (psi) (Avg. of 4 Tests) | Flexural Modulus (Avg. of 4 Tests) |
|---|---|---|---|---|
| | Glass | Resin | | |
| #1 3 hrs. at 180°F<br>2 hrs. at 250°F | #143 Cloth<br>E Glass<br>(Volan A Finish) | X2638.6/MNA/BDMA | 102,995 | $4.278 \times 10^6$ |
| #2 3 hrs. at 180°F<br>2 hrs. at 250°F<br>2 hrs. at 400°F | #143 Cloth<br>E Glass<br>(Volan A Finish) | X2638.6/MNA/BDMA | 115,755 | $4.432 \times 10^6$ |

TABLE 4

3-Inch Diameter by 9-Inch Long Burst Test Cylinders

| Code Drawing 1A35798 | Material | | Effective Wall (t) Inches | Ten. Modulus x $10^6$ psi | Burst Pressure psi | Hoop Stress | |
|---|---|---|---|---|---|---|---|
| | Glass | Resin | | | | Laminate psi | Glass psi |
| -501 #5 | HTS Single End | X2638.6/MNA/BDMA | .019 | 7.32 | 2860 | 232,000 | 358,000 |
| -501 #6 | HTS Single End | X2638.6/MNA/BDMA | .019 | 7.26 | 2580 | 206,000 | 323,000 |

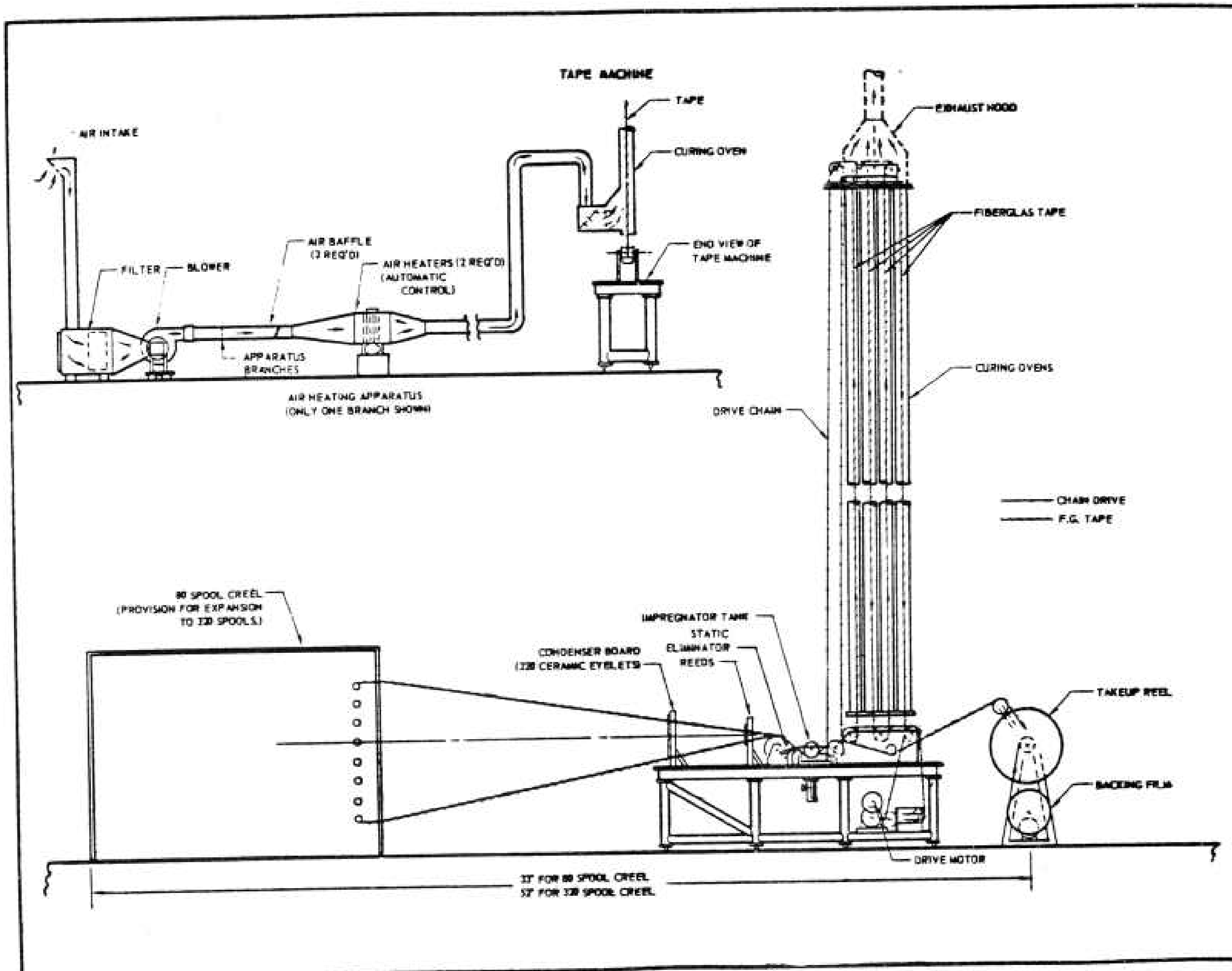
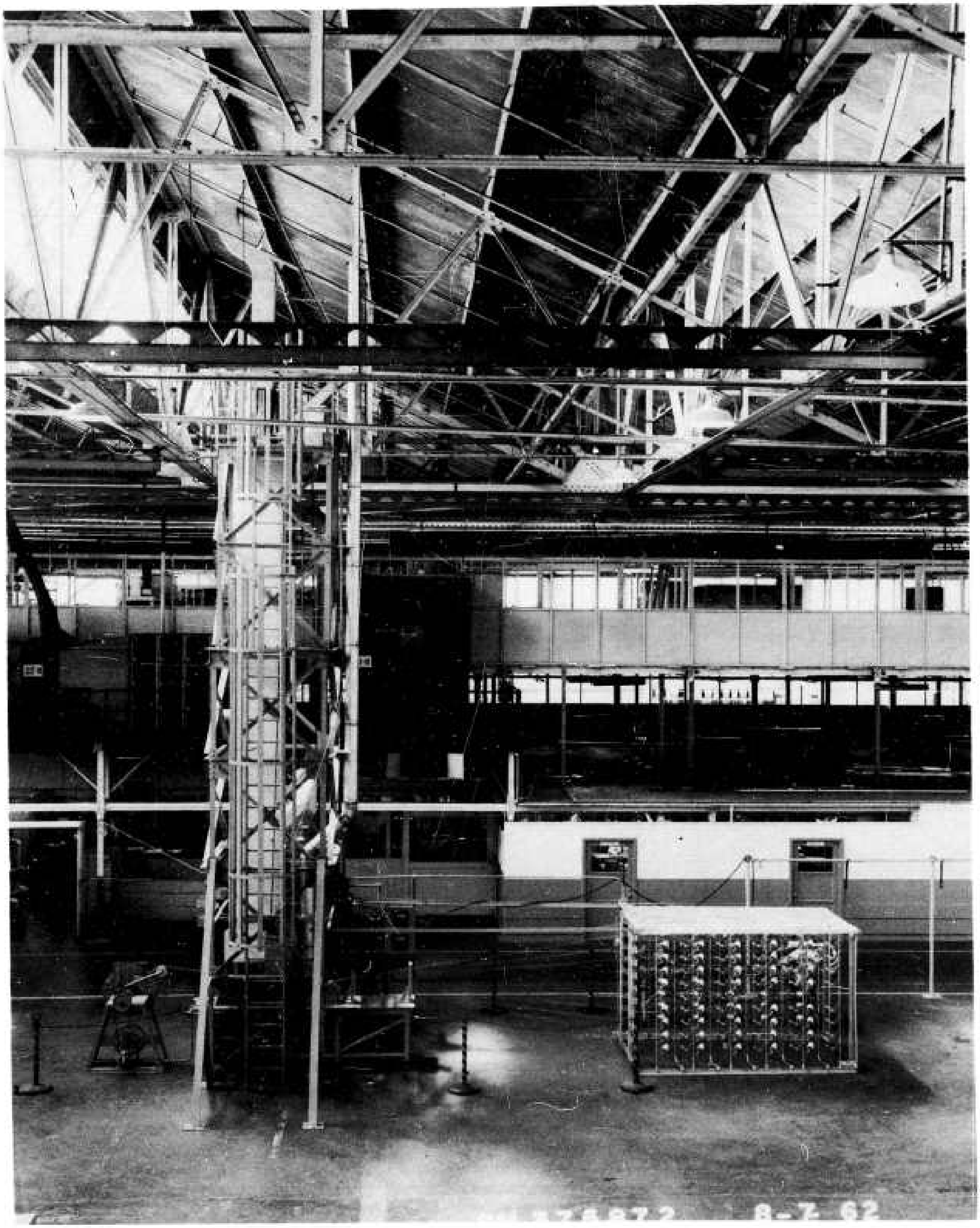
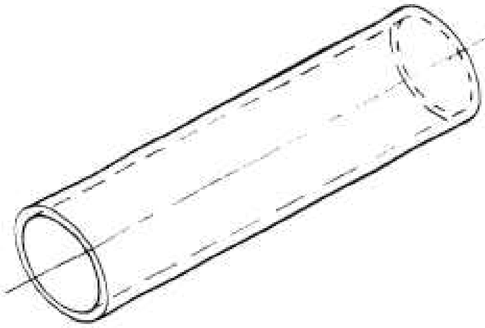



**FIGURE 1**
Fiberglas Tape-Making Machine (Schematic)

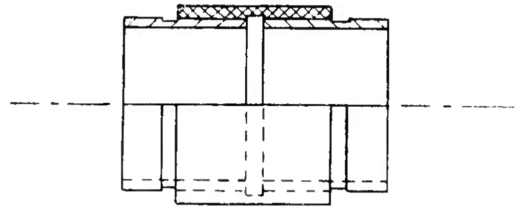


FIBERGLAS TAPE-MAKING MACHINE

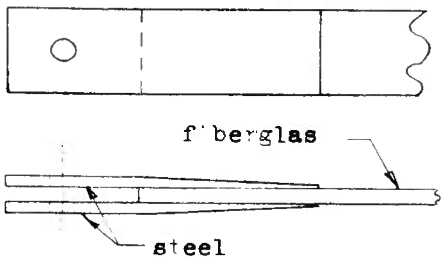
**FIGURE 2**



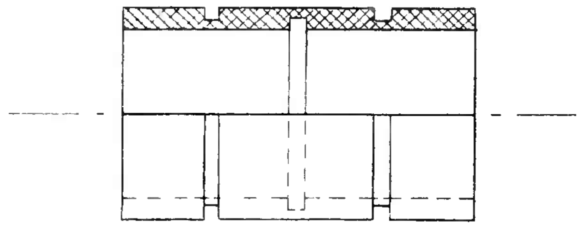
3-In. Dia. by 9-In. Long Burst Test Cylinders (Dwg. No. 1A35798)



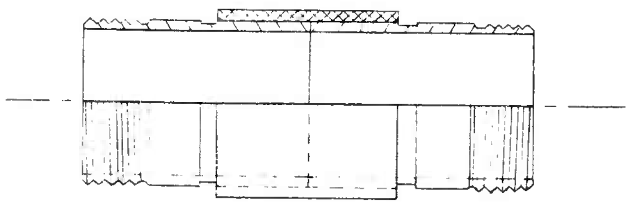
4-In. Dia. by 4-1/2-In. Long Interlaminar Shear, Metal-to-Glass, Compression Test Specimens (Dwg. No. 1A35799)



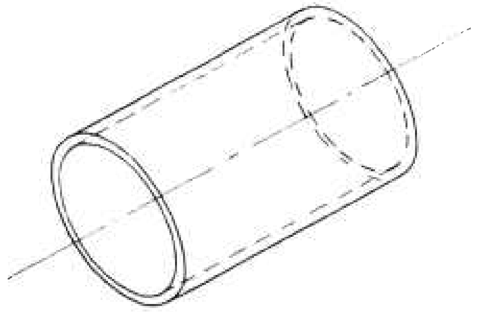

Lap Joint Specimens (Dwg. No. 1A39050)



4-In. Dia. by 6-In. Long Interlaminar Shear, Fiberglas-to-Fiberglas, Compression Test Specimens (Dwg. No. 1A35800)

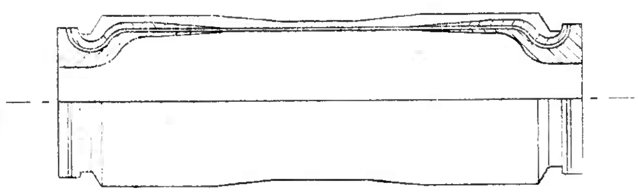


4-In. Dia. by 9-In. Long Interlaminar Shear, Metal-to-Glass, Tension Test Specimens (Dwg. No. 1A35801)

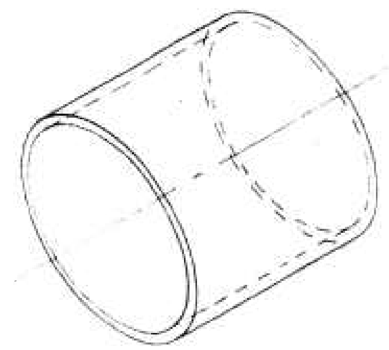


16-In. Dia. by 12-In. Long Compression Test Cylinders (Dwg. No. 1A35802)

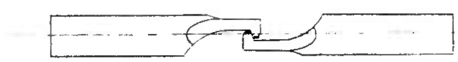
Figure 3. Bench Test Specimens.



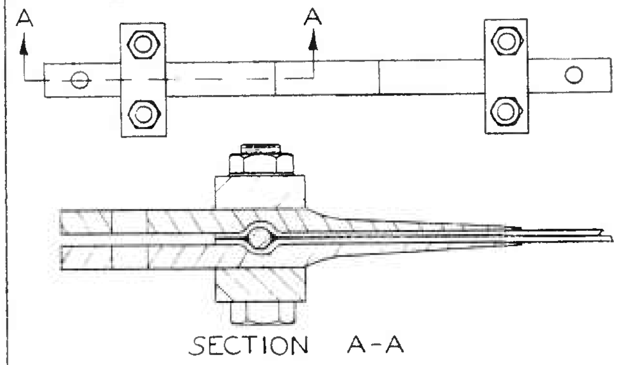
6-In. Dia. by 18-In. Long Segmented Joint Test Specimen (Dwg. No. 1A35804)



25-1/2-In. Dia. by 20-In. Long Compression Test Cylinders (Dwg. No. 1A35803)



Clamp Pull Test (Dwg. No. 1A39417)




Wedge Shear Test (Dwg. No. 1A39826)

Figure 4. Bench Test Specimens (Continued)

have been tested in addition to the twelve cylinders reported in Quarterly Progress Report No. 1. The two specimens were tested to determine the effects of using a cure cycle of 4 hours at 120°F, 2 hours at 180°F, and 2 hours at 250°F instead of a cure cycle of 2 hours at 200°F and 3 hours at 400°F as was used on the -501 cylinders reported in Report No. 1. These cylinders were tested in the same way as described in Report No. 1 for the first twelve cylinder tests (i.e., the cylinders were pressurized internally with water until failure). Failure was in hoop-tension in the circumferential wrap, and occured in both cylinders at their approximate midpoint. The test results are presented in Table 4 and indicate that lower strengths are obtained when using a "120-180-250°F" cure instead of a "200-400°F" cure. However, the data is inconclusive since the outer fibers of the cylinders were too dry (too low a resin content). This situation might have caused premature failure. The percent of resin content was not obtained for these specimens because they shattered at failure.

### 2.5.2 Lap Joint Specimens

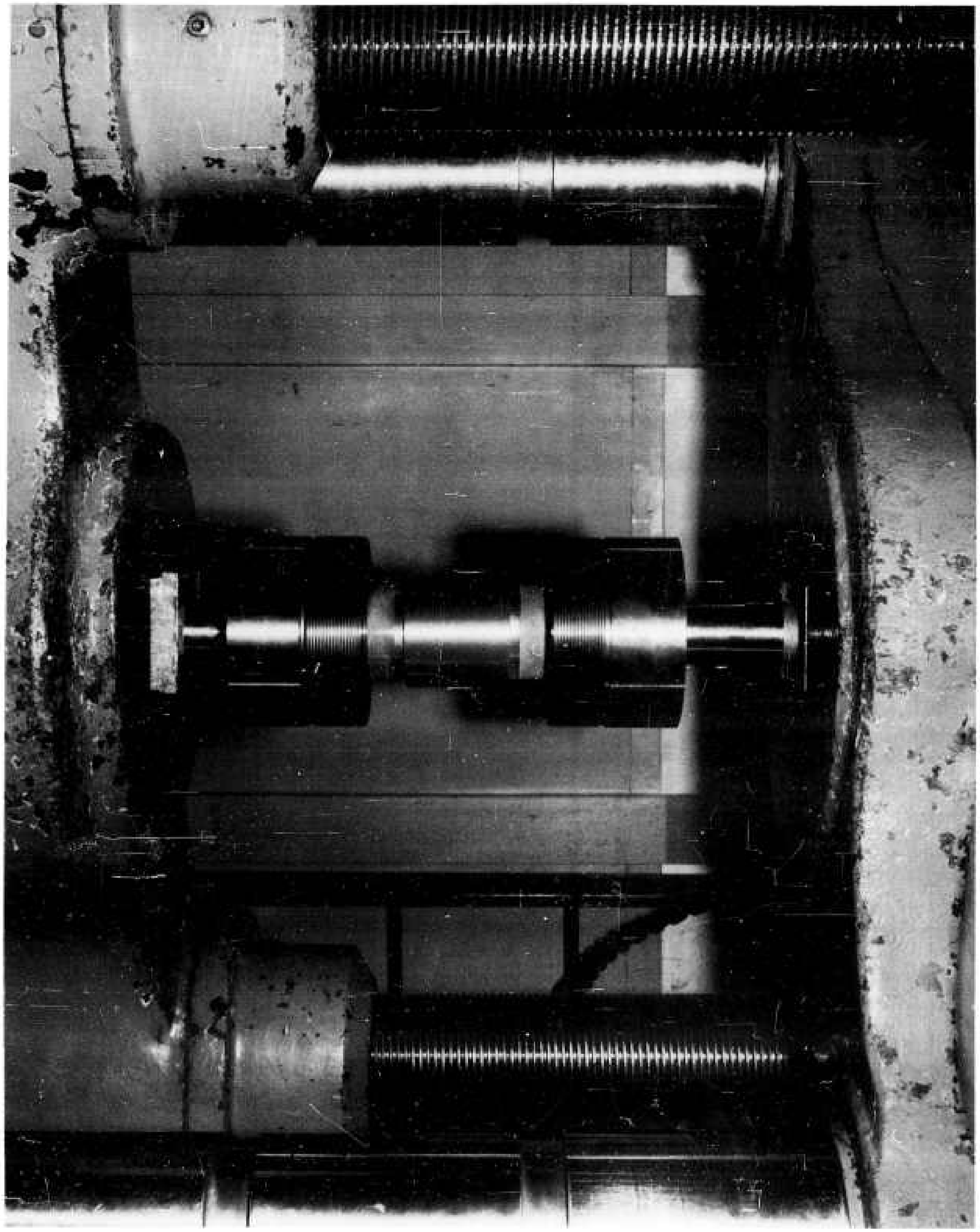
Eighteen lap joint specimens (Dwg. No. 1A39050) have been fabricated in addition to the fifteen specimens tested and reported in Report No. 1. These specimens were made by bonding tapered steel end fittings to a fiberglas laminate. They will be tested to evaluate the bond strength of different adhesives. Three specimens for each of six different adhesives are now ready for test. Tapered end fittings were used since data from the first fifteen lap joint tests (see Section 2.2.2.1.2 of Quarterly Progress Report No. 1) showed that this configuration develops the most strength.

2.5.3 4-In. Dia. by 9-In. Long Interlaminar Shear Tension Test Specimens

Ten 4-in. dia. by 9-in. long interlaminar shear tension test specimens (Dwg. No. 1A35801) have been tested. Six of these specimens were tested to determine the ultimate shear strength of a fiberglas to metal bond using FM-97 adhesive. The remaining four specimens were fabricated using modified fittings salvaged from the first six specimens tested. They were tested to evaluate the effect of modifications of the fittings on the shear strength values.

The first six specimens tested were fabricated using steel end fittings which had been vapor degreased, grit blasted, and cleaned with acetone. The end fittings were assembled on a mandrel and FM-97 film adhesive was applied. Forty-two plies of "B"-staged tapes were laid up to form the longitudinal laminate The "longitudinals" overlapped the fittings of the -1, -501, and -503 specimens 1-inch, 2-inches, and 3-inches respectively to give various shear areas. Forty-two plies of circumferential wrap were then applied over the "longitudinals." One hundred ends of HTS glass per inch per ply of circumferential wrap were used. The assembly was cured 4 hours at 120°F, 2 hours at 180°F, and 2 hours at 250°F.

Each of the six specimens were mounted in a Baldwin 400,000 pound tension-compression machine (see Figure 5). A test jig with spherical seating was used so that the parts would align automatically under load (see Figure 6). The specimens were loaded at a uniform rate until failure. Results are shown in Table 5. Load versus deflection was recorded for each specimen. (See Figure 7 for typical load versus deflection plot.)



TEST SET-UP FOR INTERLAMINAR SHEAR TENSION TEST SPECIMENS

**FIGURE 5**


SPHERICAL NUT FOR INTERLAMINAR SHEAR TENSION TEST JIG

**FIGURE 6**

TABLE 5

4-In. Dia. by 9-In. Long Interlaminar Shear Tension Test Specimens

| Code Drawing 1A35801 | | Material | | | | Length of Shear Joint (In.) | Shear Stress | |
|---|---|---|---|---|---|---|---|---|
| | | Metal | Glass | Resin | Adhesive | | Tension psi | Compression psi |
| -1 | #1 | 4140 Steel Tube | HTS Single End | X2638.6/MNA/BDMA | FM 97 | 1 | 64* | 250* |
| -1 | #2 | 4140 Steel Tube | HTS Single End | X2638.6/MNA/BDMA | FM 97 | 1 | 1480 | 1530 |
| -501 | #1 | 4140 Steel Tube | HTS Single End | X2638.6/MNA/BDMA | FM 97 | 2 | 2920 | 1710 |
| -501 | #2 | 4140 Steel Tube | HTS Single End | X2638.6/MNA/BDMA | FM 97 | 2 | 1870 | 1830 |
| -503 | #1 | 4140 Steel Tube | HTS Single End | X2638.6/MNA/BDMA | FM 97 | 3 | 2100 | 1960 |
| -503 | #2 | 4140 Steel Tube | HTS Single End | X2638.6/MNA/BDMA | FM 97 | 3 | 2320 | 1540 |

*No bond adhesion to steel.

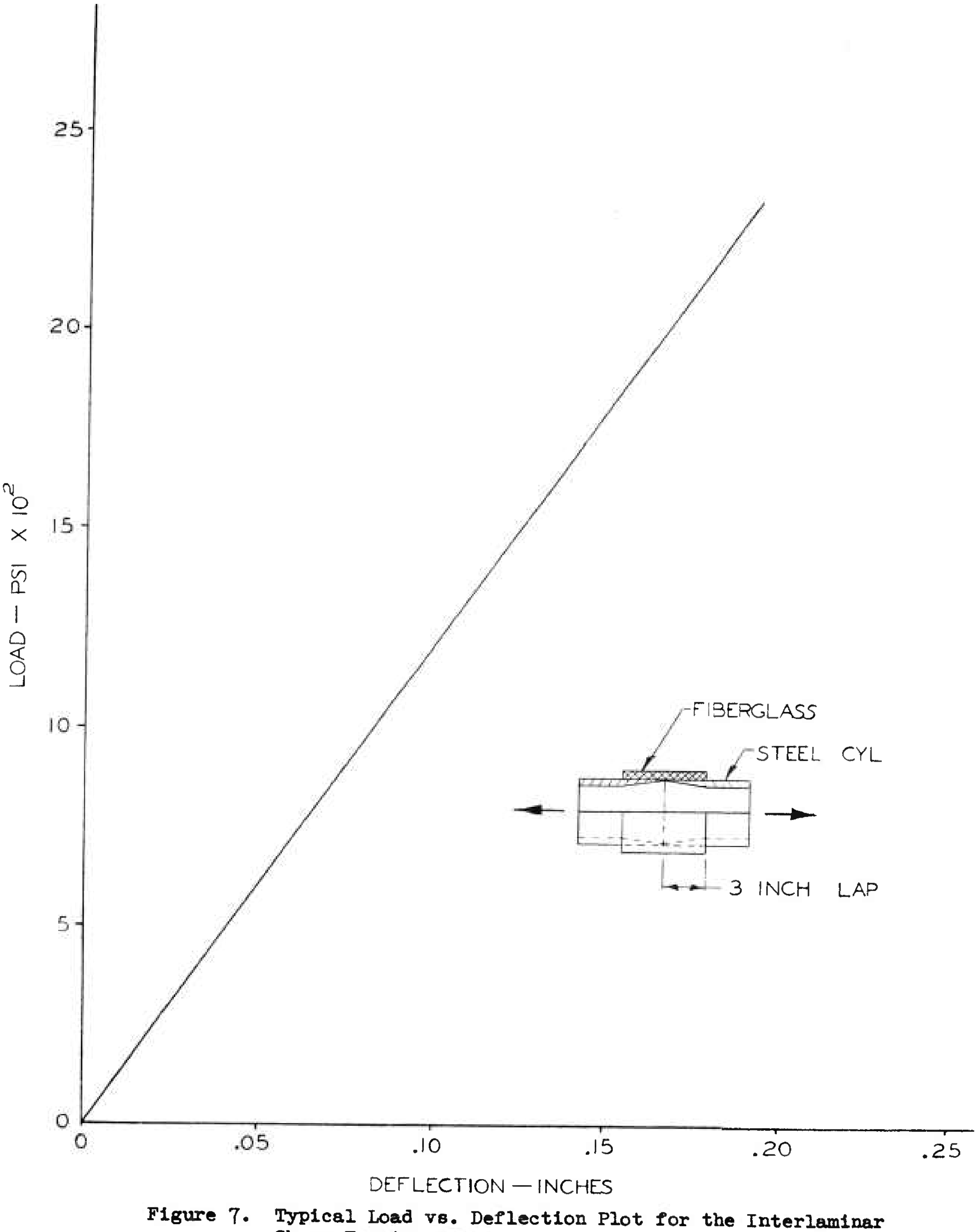
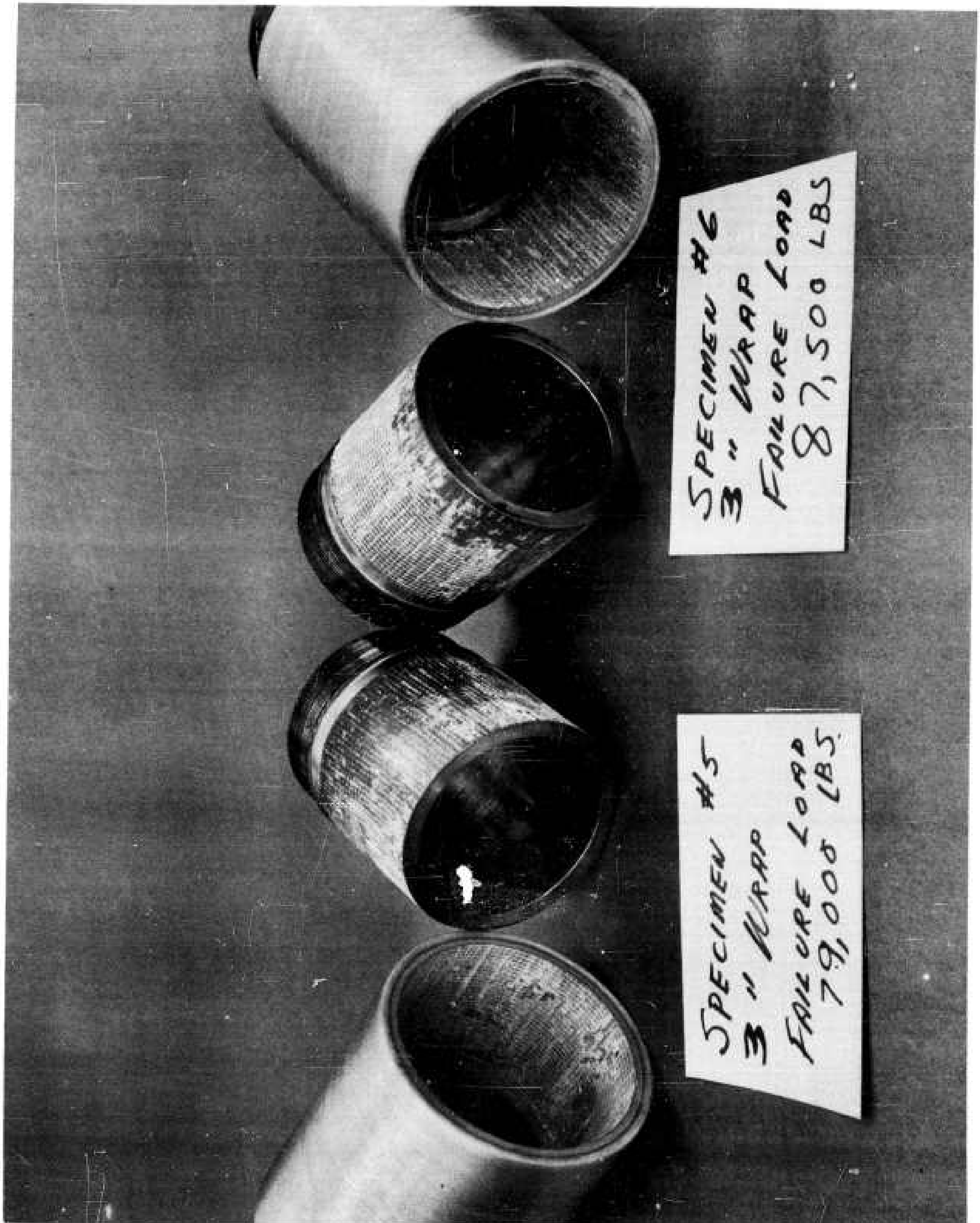



**Figure 7.** Typical Load vs. Deflection Plot for the Interlaminar Shear Tension Tests.

All six specimens failed in the bond material except the No. 1 specimen of 1A35801-1 (see Figure 8). The No. 1 specimen of -1 failed prematurely because the adhesive had not bonded to the steel. This lack of bonding is probably due either to faulty fabrication or to deterioration of the FM-97 which had been left at room temperature for a week.

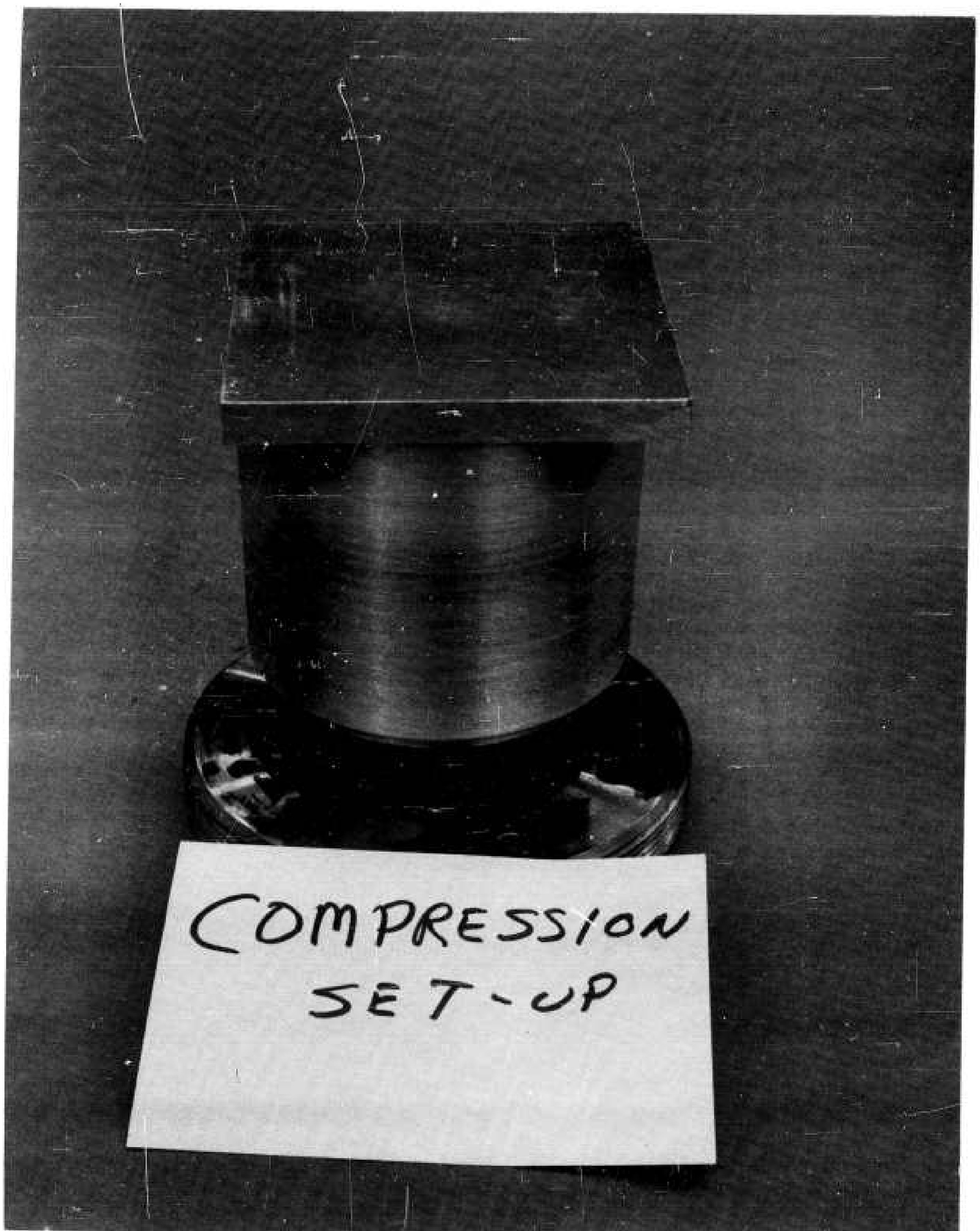
Failure in all six specimens occurred at one end only. The ends which had not failed were prepared as shown in Figure 9 and loaded in compression in the Baldwin tension-compression machine until they failed. Compressive failure loads are presented in Table 5. Since the specimens were designed for tension tests, there was no guarantee that opposite faces of the specimens were parallel. Compressive failures might have occurred prematurely if the faces were not parallel.

The remaining four interlaminar shear test specimens were fabricated using "notched" or "tapered" fittings salvaged from 1A35801-501 and -503 tests described above. Each "notched" specimen used salvaged 1A35801-501 fittings (with a 2-inch shear length) that were reworked by machining a .040-inch deep by 1/2 inch radius notch 1 inch from the inside end of the fittings. Each "tapered" specimen was made from salvaged 1A35801-503 fittings (with a 3-inch shear length) that were reworked by tapering the original constant .312-inch thickness to .063-in. in a length of 3 inches. The four reworked specimens were assembled identically to the first six specimens except as follows: The steel fittings were treated with Pre-Bond 700 (an alkaline cleaner). The FM-97 film adhesive was applied immediately upon removal from refrigerated storage. Sixteen plies of 20-end HTS rovings were used for circumferential wrap instead of 42 plies of single end HTS. Also, the assembly was cured for



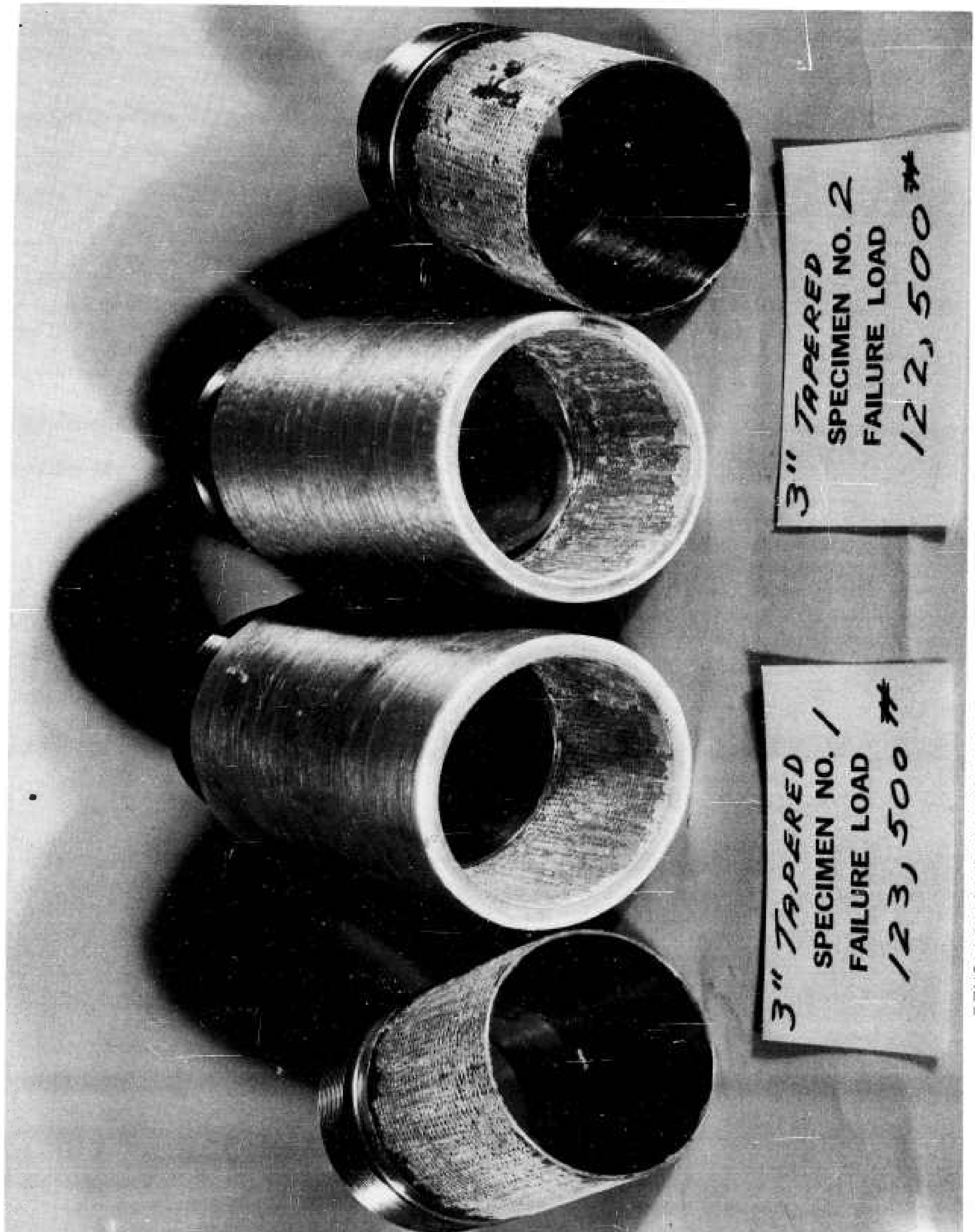

TYPICAL INTERLAMINAR SHEAR TENSION TEST SPECIMENS (AFTER FAILURE)

**FIGURE 8**



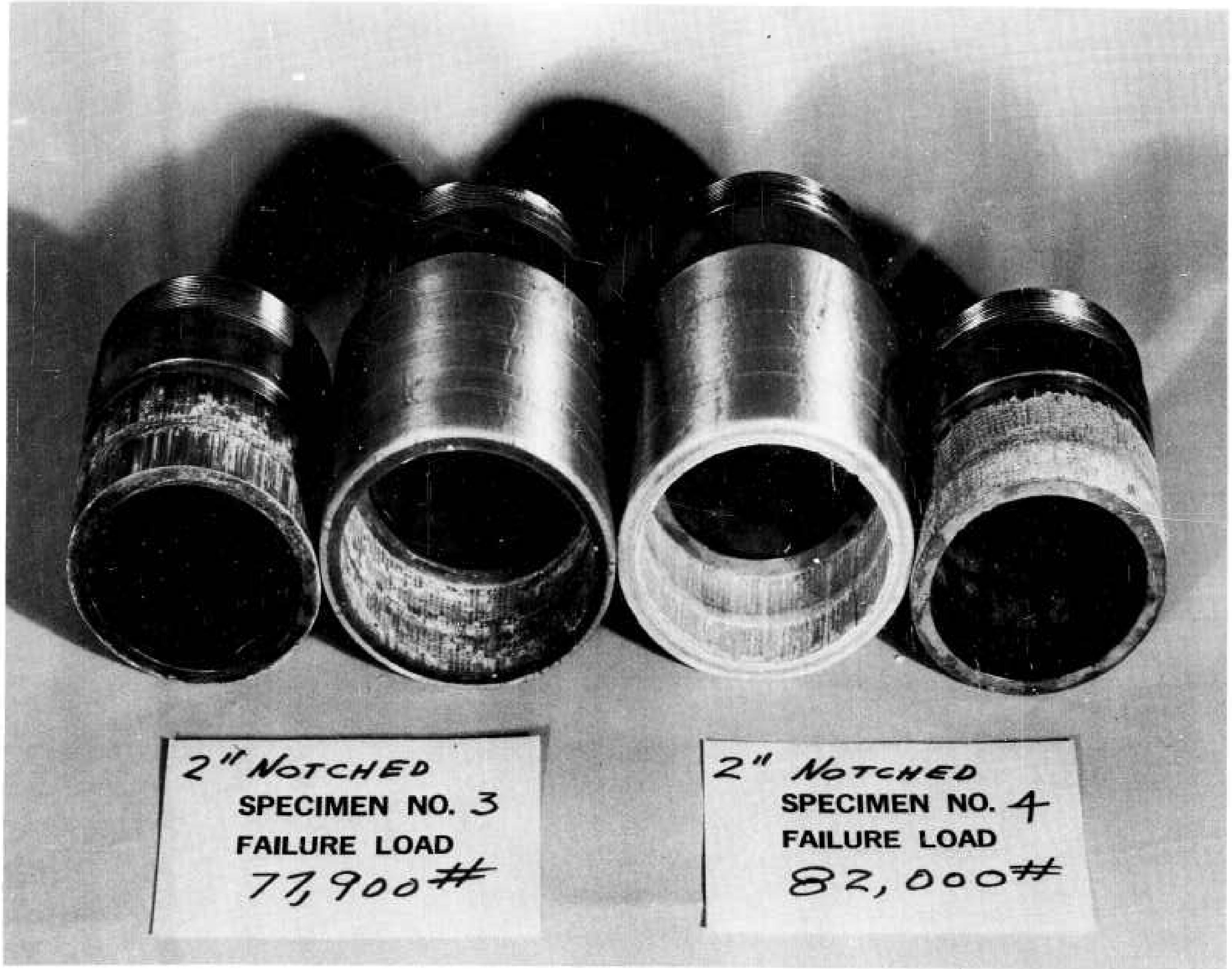

COMPRESSION TEST SET-UP FOR UNFAILED ENDS OF INTERLAMINAR SHEAR TENSION TEST SPECIMENS

**FIGURE 9**




REWORKED INTERLAMINAR SHEAR TENSION TEST SPECIMENS (AFTER FAILURE)

**FIGURE 10**




REWORKED INTERLAMINAR SHEAR TENSION TEST SPECIMENS (AFTER FAILURE) (CONT'D)

**FIGURE 11**

2 hours at 120°F, 4 hours at 180°F, and 4 hours at 250°F instead of for 4 hours at 120°F, 2 hours at 180°F, and 2 hours at 250°F.

The four reworked specimens were tested in tension and compression in the same way as described for the first six specimens. Results are shown in Table 6. All four reworked specimens failed in the adhesive (see Figures 10 and 11).

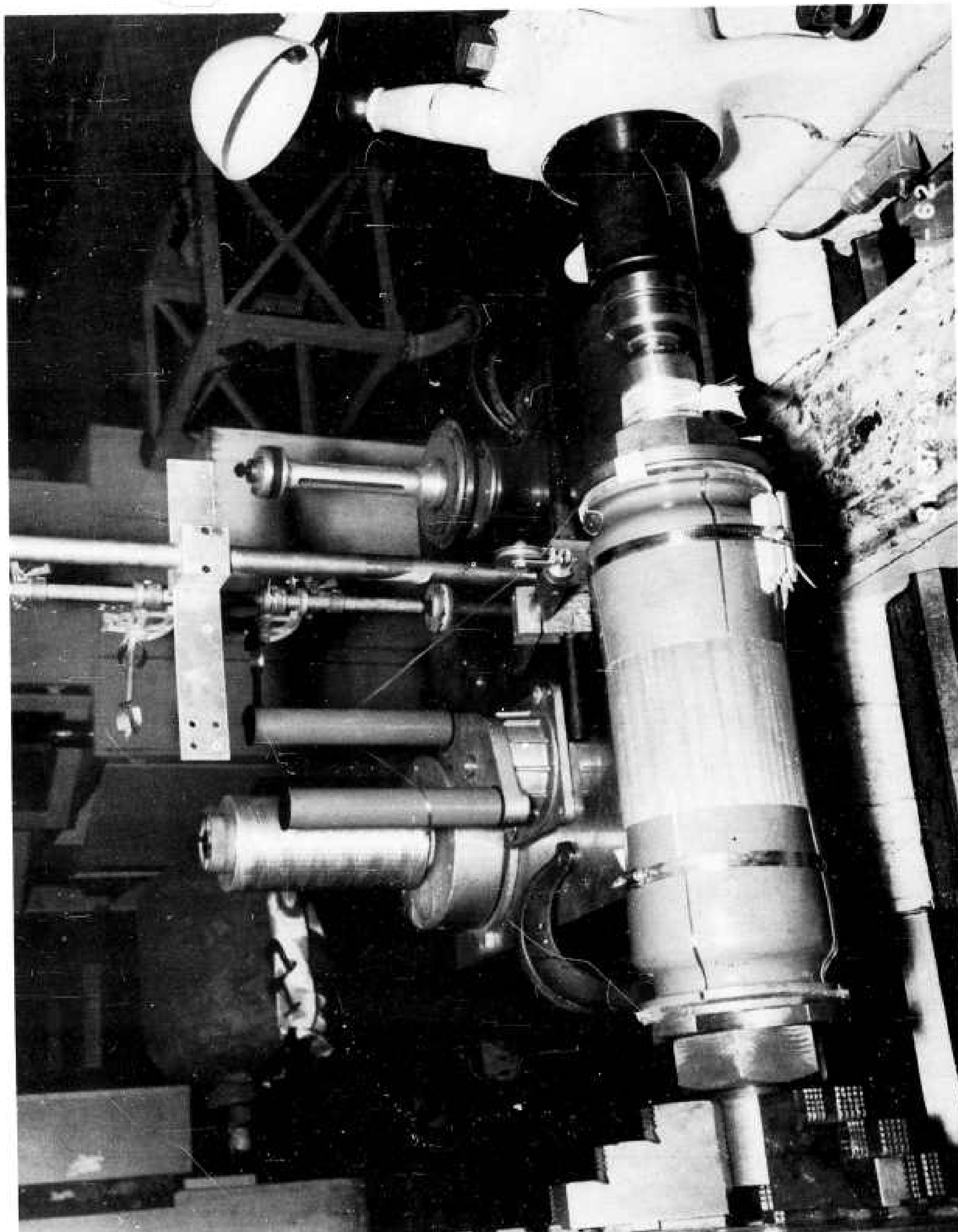
2.5.4 6-In. Dia. by 18-In. Long Segmented Joint Test Specimens

One of the six 6-in. dia. by 18-in. long segmented joint test specimens (Dwg. No. 1A35804) has been tested. The specimen was fabricated on a salt mandrel as follows: All steel end fittings were vapor degreased, grit blasted, cleaned, and primed with 226A primer (to assist application of adhesive film). The inner ring end fittings were then installed on the mandrel and four plies of 20-end HTS USP (U S Polymeric) E 714 pre-preg were wound between the end fittings to provide a level surface for the longitudinals. FM-97 film adhesive was applied to the end fittings and 27 plies of 1/2-inch wide Douglas pre-preg tape were laid up to form longitudinals. The segmented end fittings were cleaned, the same as the inner ring end fittings, and installed. Then E 714 pre-preg circumferential wrap was applied (see Figure 12). The assembly was cured 3 hours at 180°F and 4 hours at 250°F. The salt mandrel was then washed out and the part post-cured 4 hours at 350°F (the temperature was raised to 350°F in 50°F increments over a 1-1/2 hour period). The part was cooled too rapidly after post-cure and as a result, circumferential cracks developed. These cracks were enlarged by torsional loads applied during final machining of the specimen ends.

TABLE 6

4-In. Dia. by 9-In. Long Interlaminar Shear Tension Test Specimens (Reworked)

| Code Drawing 1A35801 | Material | | | | Length of Shear Joint (In.) | Rework | Shear Stress | |
|---|---|---|---|---|---|---|---|---|
| | Metal | Glass | Resin | Adhesive | | | Tension psi | Compression psi |
| -501 #1 | 4140 Steel Tube | HTS Single End | X2638.6/MNA/BDMA | FM 97 | 2 | Notched | 3,090 | 2,420 |
| -501 #2 | 4140 Steel Tube | HTS Single End | X2638.6/MNA/BDMA | FM 97 | 2 | Notched | 3,260 | 1,750 |
| -503 #1 | 4140 Steel Tube | HTS Single End | X2638.6/MNA/BDMA | FM 97 | 3 | Tapered | 3,270 | 2,700 |
| -503 #2 | 4140 Steel Tube | HTS Single End | X2638.6/MNA/BDMA | FM 97 | 3 | Tapered | 3,250 | 2,890 |



FABRICATION OF SEGMENTED JOINT TEST SPECIMEN

FIGURE 12

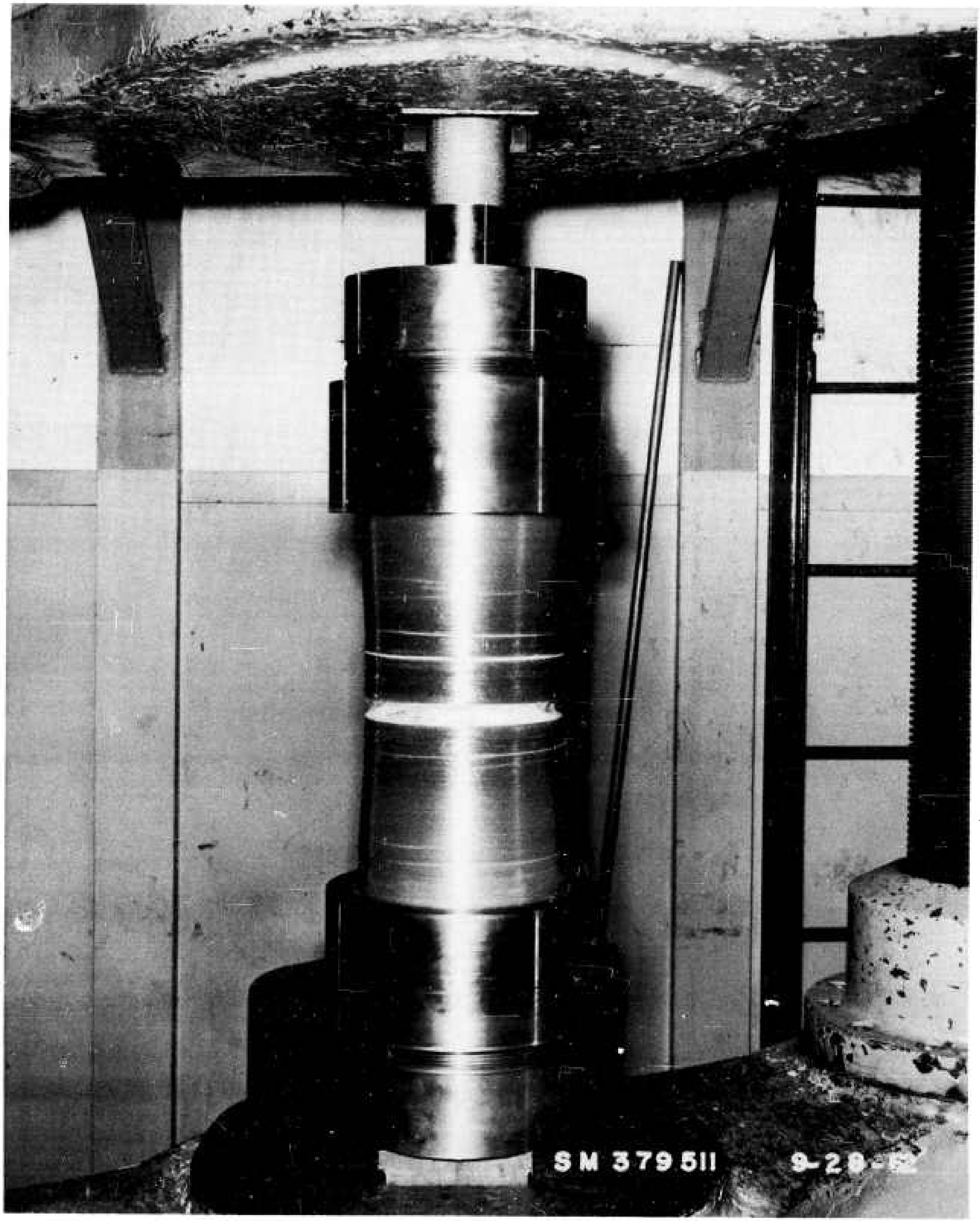
The specimen was tested in a 400,000 lb. Baldwin compression-tension machine (see Figure 13). It was loaded in tension until it failed. Failure occurred at 228,000 lbs. Investigation showed that the fiberglas-to-metal bond (FM-97) had failed, thereby allowing the longitudinal laminate (stave) to pull out of the joint (see Figure 14). Failure of the bond is believed to be due to deterioration of the FM-97 while at room temperature.

A second joint-test specimen has been completed using Lefkoweld No. 157 paste adhesive instead of FM-97. This specimen will be tested within one week. Circumferential cracks in the specimen were prevented by cooling the specimen more gradually after post-cure and by being more careful with the specimen during final machining.

The remaining four joint test specimens will be fabricated and tested at the rate of one per week. This staggered fabrication and testing schedule has been adopted so that any modifications indicated by test results can be integrated into the design and fabrication of subsequent specimens. The four specimens will be constructed with premolded staves instead of "hand laid" longitudinals. Excellent results were obtained with several "trial-run" premolded staves which were formed using matched dies (see Figures 15 & 16). These premolded staves were made by winding E 714 pre-preg on an "end-over-end" form (see Figure 17). The windings were then removed from the form and press-molded between matched dies at 300°F.

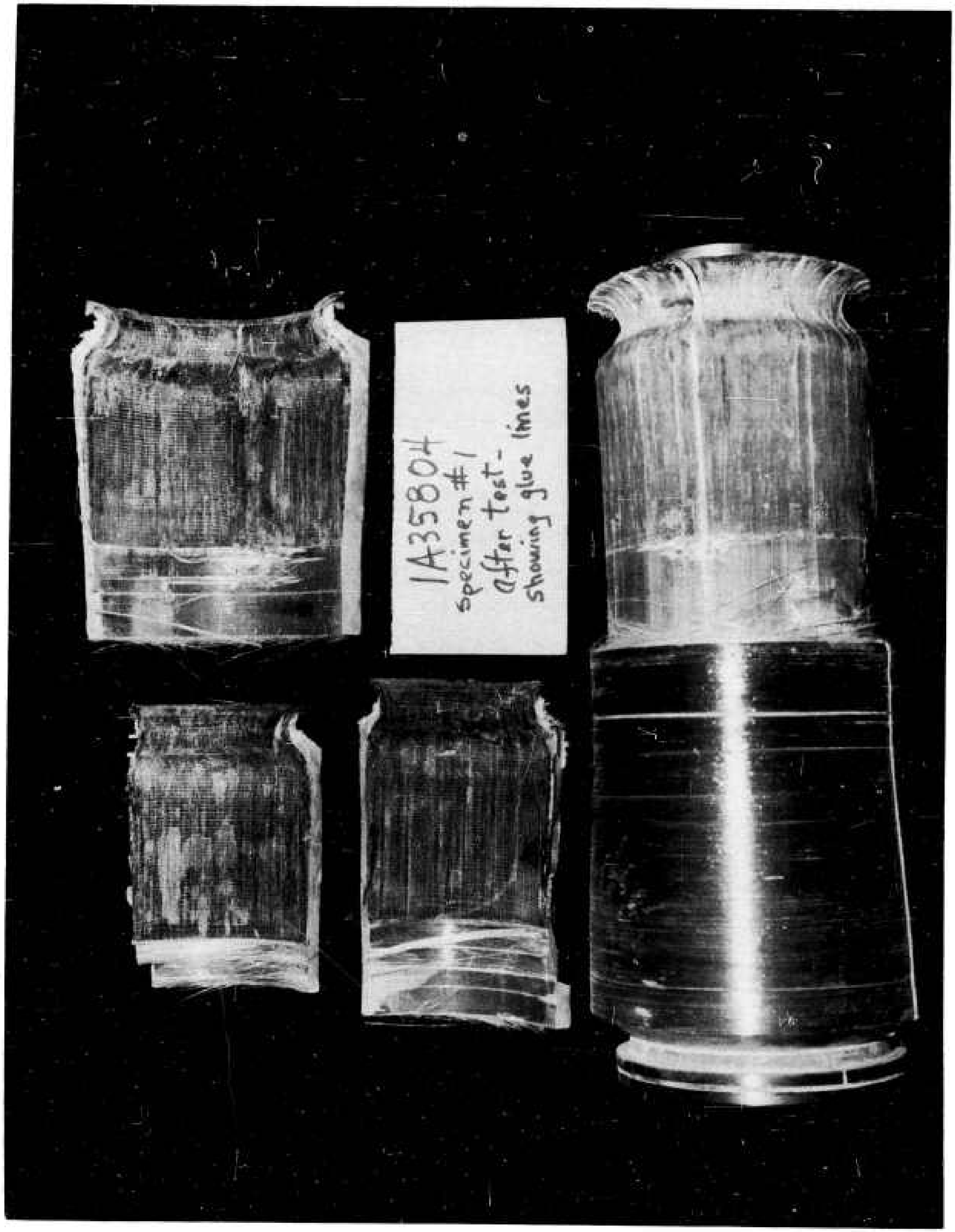
2.5.5 <u>4-In. Dia. by 4-1/2-In. Long Interlaminar Shear, Metal to Glass, Compression Test Specimens</u>

Six 4-in. dia. by 4-1/2-in. long interlaminar shear, metal to



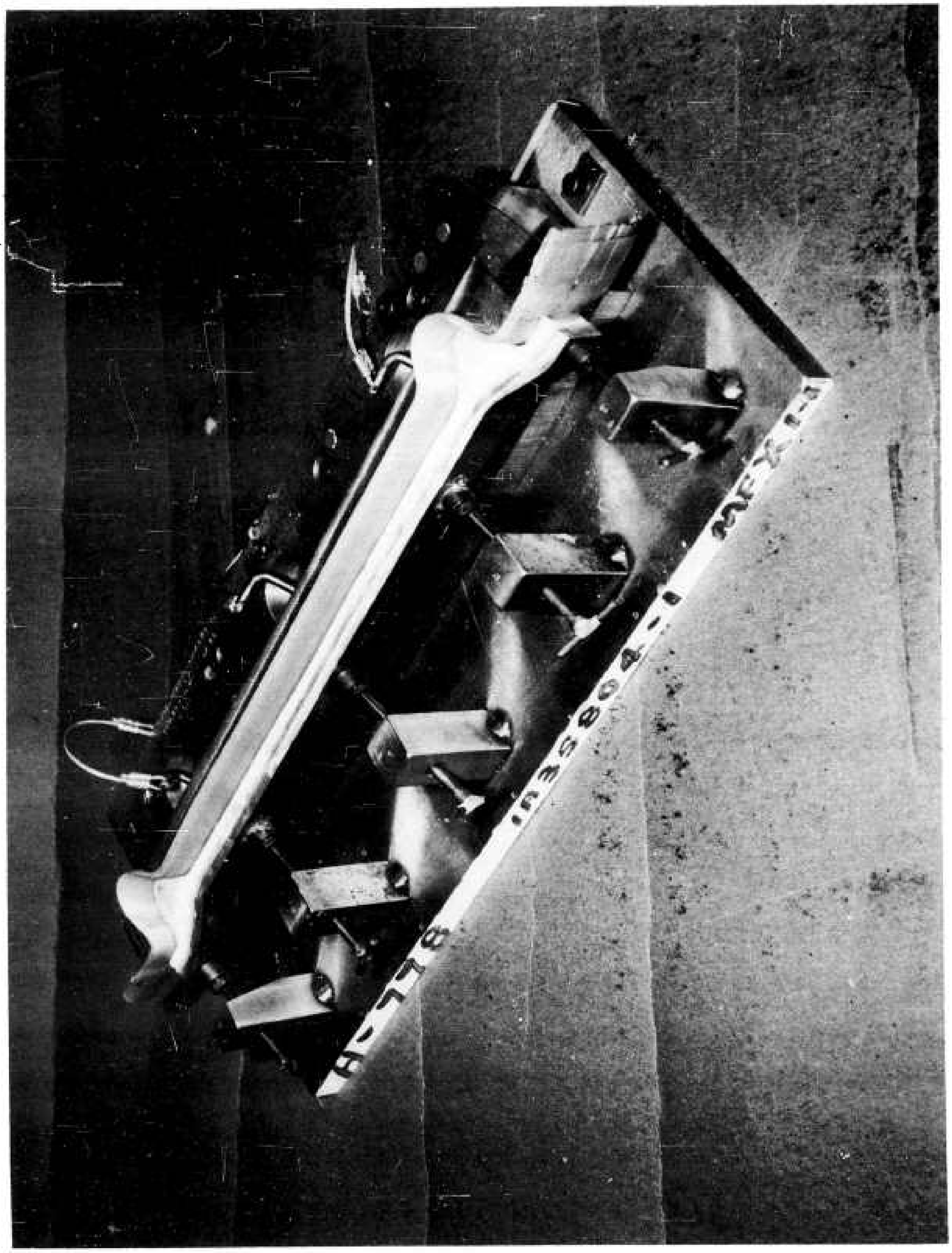

TEST SET-UP FOR SEGMENTED JOINT TEST SPECIMEN (AFTER FAILURE)

**FIGURE 13**



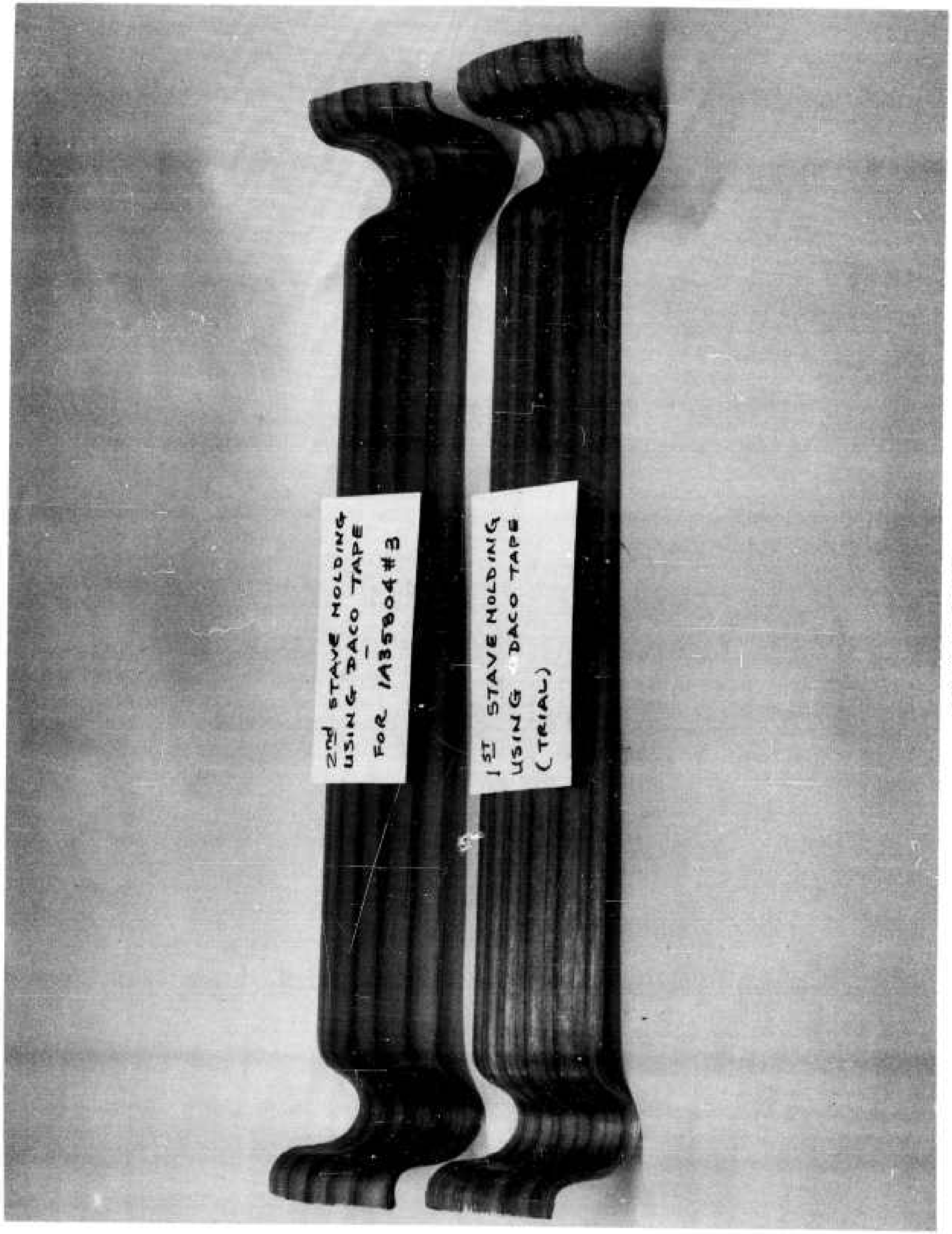

DISSECTED SEGMENTED JOINT TEST SPECIMEN (AFTER FAILURE)

**FIGURE 14**



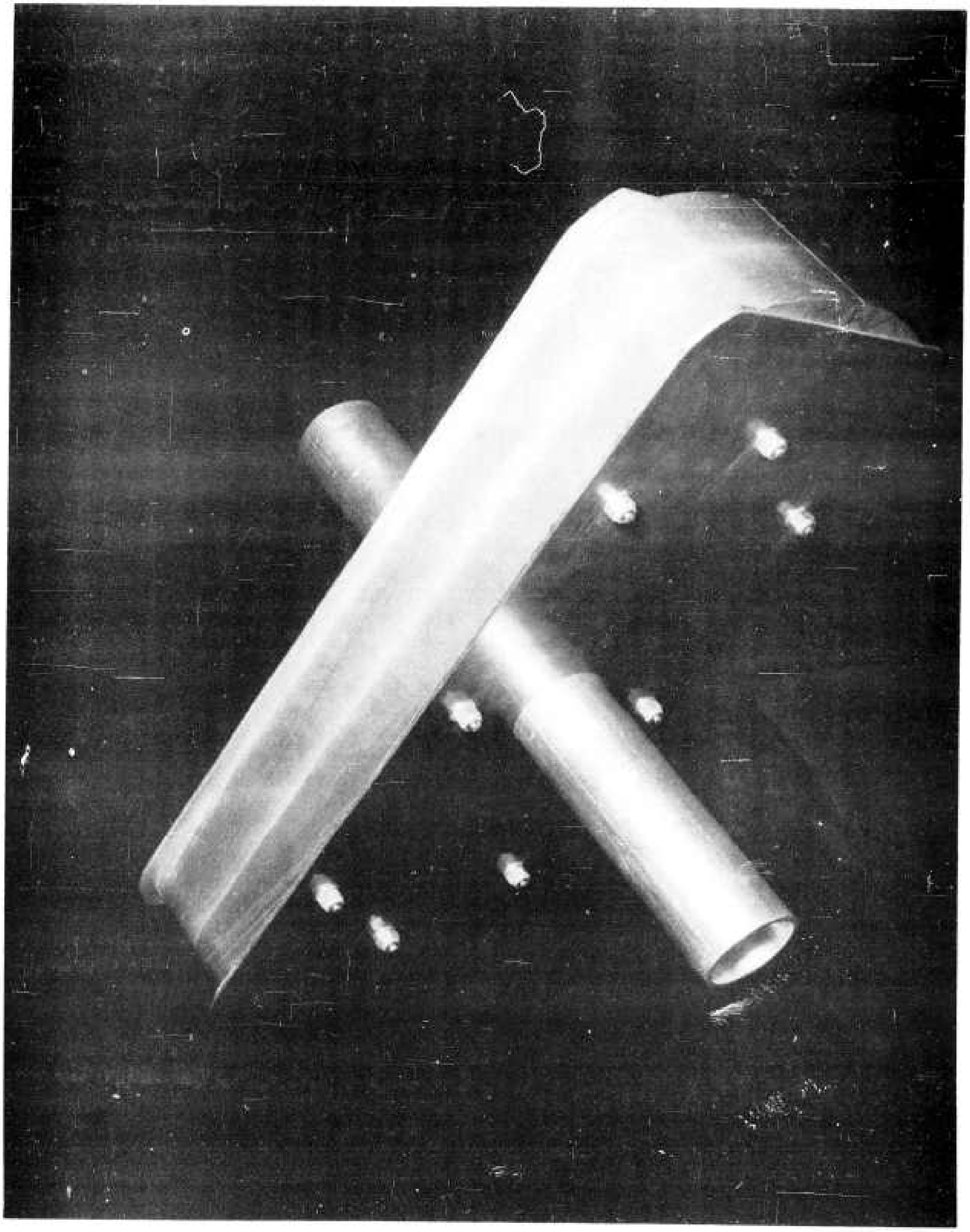
MATCHED DIES FOR FORMING PREMOLDED STAVES

**FIGURE 15**




PREMOLDED STAVES

**FIGURE 16**



"END-OVER-END" FORM FOR CONSTRUCTION OF PREMOLDED STAVES

FIGURE 17

glass, compression test specimens (Dwg. No. 1A35799) have been tested. The No. 1, -1; No. 2, -1; and No. 1, -503 specimens were fabricated as follows: 4140 steel fittings were vapor degreased, grit blasted, and washed with acetone. FM-97 film adhesive was "heat-tacked" to the steel. Sixty-six plies of "interim" tape (impregnated with 2638.6 resin) were applied to form the longitudinal laminate. The "longitudinals" overlapped the fittings of the -1, -501, and -503 specimens 1/2 inch, 1 inch, and 1-1/2 inches respectively to give various shear areas. Twenty plies of circumferential wrap were applied over the "longitudinals." One hundred and ten ends of single end HTS glass per inch per ply of circumferential wrap were used. The assembly was cured 4 hours at 120°F, 3 hours at 190°F, and 6 hours at 250°F. The No. 1, -501; No. 2, -501; and No. 2, -503 specimens were fabricated as described above except thirty-six plies of tape were used for the "longitudinals," ten plies of 20 end HTS roving were used for circumferential wrap, and the assembly was cured 4 hours at 180°F and 4 hours at 250°F.

The specimens were tested in a 400,000 lb. Baldwin compression-tension machine. They were loaded in compression until they failed (see Table 7 for test results) and load versus deflections were recorded (see Figure 18 for typical load vs. deflection plot). The portions of the specimens which failed were cut apart for inspection. (See Figure 19 for typical failure). The No. 1, 1A35799-1 specimen failed partially in the bond and partially in interlaminar shear of the fiberglas laminate. The No. 2, -1 specimen failed in the bond. Specimens No. 1, -501; No. 2, -501; and No. 1, -503 failed in interlaminar shear of the laminate. The No. 2, -503 specimen failed because the laminate had not bonded to the steel.

TABLE 7

4-In. Dia. by 4-1/2-In. Long, Interlaminar Shear, Metal to Glass, Compression Test Specimens

| Code Drawing 1A35799 | Material | | | | Length of Lap (in.) | Shear Stress (psi) | Type of Failure |
|---|---|---|---|---|---|---|---|
| | Metal | Glass | Resin | Adhesive | | | |
| -1 #1 | 4140 Steel | HTS Single End | X2638.6/MNA/BDMA | FM 97 | 1/2 | 1,800 | Bond & interlaminar |
| -1 #2 | 4140 Steel | HTS Single End | X2638.6/MNA/BDMA | FM 97 | 1/2 | 830 | Bond |
| -501 #1 | 4140 Steel | HTS Single End | X2638.6/MNA/BDMA | FM 97 | 1 | 1,390 | Interlaminar |
| -501 #2 | 4140 Steel | HTS Single End | X2638.6/MNA/BDMA | FM 97 | 1 | 2,620 | Interlaminar |
| -503 #1 | 4140 Steel | HTS Single End | X2638.6/MNA/BDMA | FM 97 | 1-1/2 | 2,210 | Interlaminar |
| -503 #2 | 4140 Steel | HTS Single End | X2638.6/MNA/BDMA | FM 97 | 1-1/2 | 175* | Bond* |

*No bond adhesion to steel.

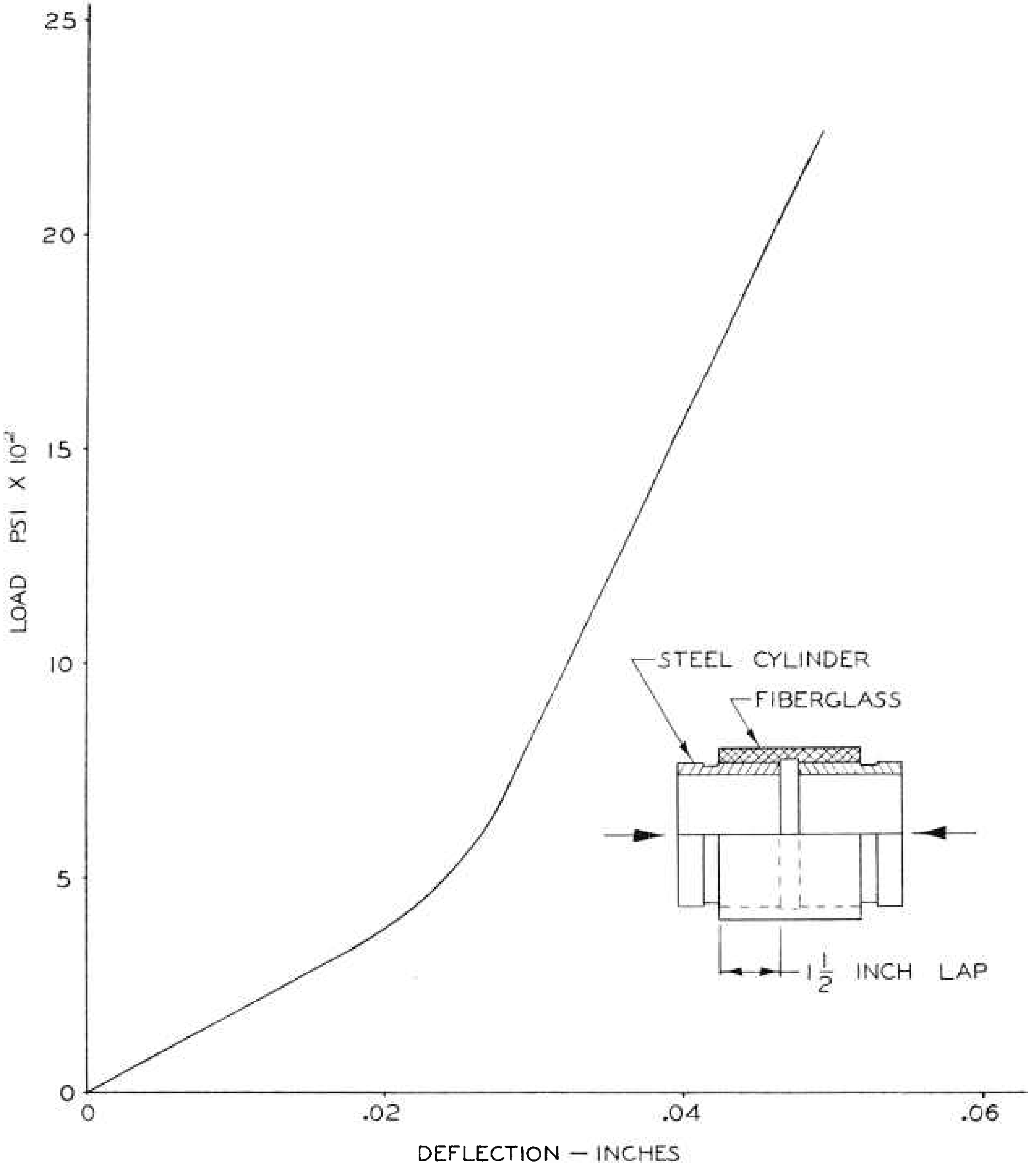



**Figure 18.** Typical Load vs. Deflection Plot for Interlaminar Shear, Metal-to-Glass, Compression Test Specimens.


TYPICAL INTERLAMINAR SHEAR, METAL TO GLASS, COMPRESSION TEST SPECIMEN

**FIGURE 19**

2.5.6 <u>4-In. Dia. by 6-In. Long Interlaminar Shear, Fiberglas-to-Fiberglas, Compression Test Specimens</u>

All six of the 4-in. dia. by 6-in. long interlaminar shear, fiberglas-to-fiberglas, compression test specimens (Dwg. No. 1A35800) have been completed. They will be tested within one week.

2.5.7 <u>16-In. Dia. by 12-In. Long Compression Test Cylinders</u>

Fabrication of two of the six 16-in. dia. by 12-in. long compression test cylinders (Dwg. No. 1A35802) has started. Fabrication is approximately two weeks behind schedule. This time lag is not serious because it will not delay the fabrication and testing of other items. All six cylinders should be completed within five weeks.

2.5.8 <u>25-1/2-In. Dia. by 20-In. Long Compression Test Cylinders</u>

Tooling for the 25-1/2-in. dia. by 20-in. long compression test cylinders (Dwg. No. 1A35803) should be completed within two weeks. A small glass fabric cylinder has been constructed to assist Elastomer Research in casting tests of inert propellants (plastisols) which will be suitable for casting into the 25-1/2-in. dia. compression cylinders. A suitable plastisol with a tensile modulus of 200 psi at room temperature has been developed. However, 800 psi plastisols are cracking on surfaces exposed to oven heat and air. A solution to this problem is being sought.

2.5.9 <u>Clamp Pull Test</u>

A clamp pull test (Dwg. No. 1A39417) has been performed to verify 43-in. dia. segment clamp strength. The simulated clamps were "assembled" and loaded to 24,000 lbs. tension in a Baldwin 400,000 pound tension-compression machine as shown in Figure 20. The clamps slipped apart at this load. Misalignment of the clamps probably caused them to slip apart. The clamps for joining the 43-in. dia. subscale segments are not expected to slip off during burst testing since they will be correctly aligned during installation. If the clamps are correctly aligned, then friction forces and a restraining band (see Figure 22) will prevent slippage. The clamps were "reassembled" and a C-clamp was installed to insure alignment of the parts during test. The clamps were reloaded and failed (by shearing of the small clamp leg as shown in Figure 21) at 39,000 lbs., or 145 percent of design ultimate load.

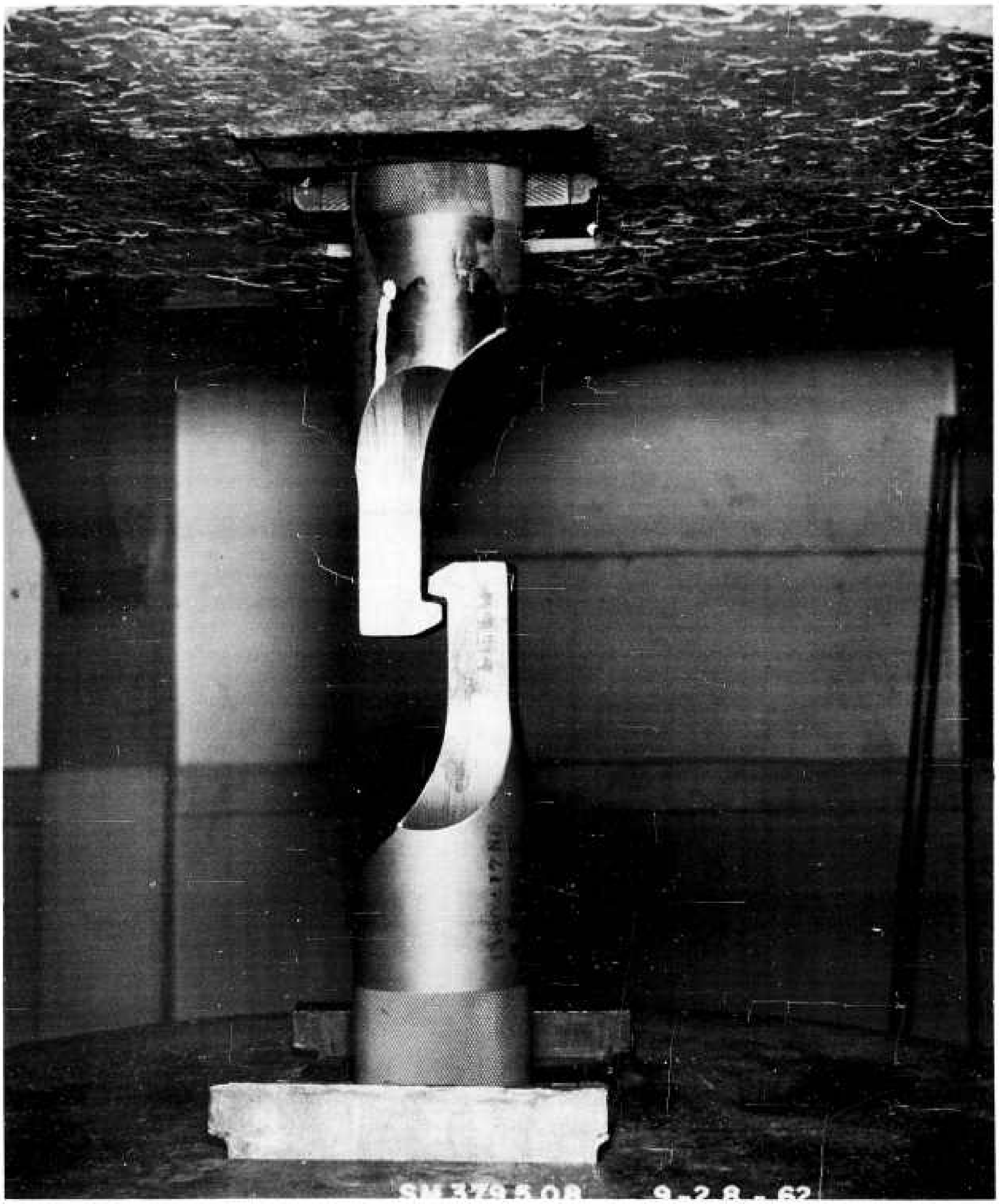
### 2.5.10 Wedge Shear Test

A wedge shear test (Dwg No. 1A39826) has been added to the bench test program. This test (see Figure 4) will be used to evaluate a new stave anchoring concept which may prove superior to the existing anchoring concept. Detail parts for the test are being fabricated.

## 2.6 43-In. Dia. Subscale segments

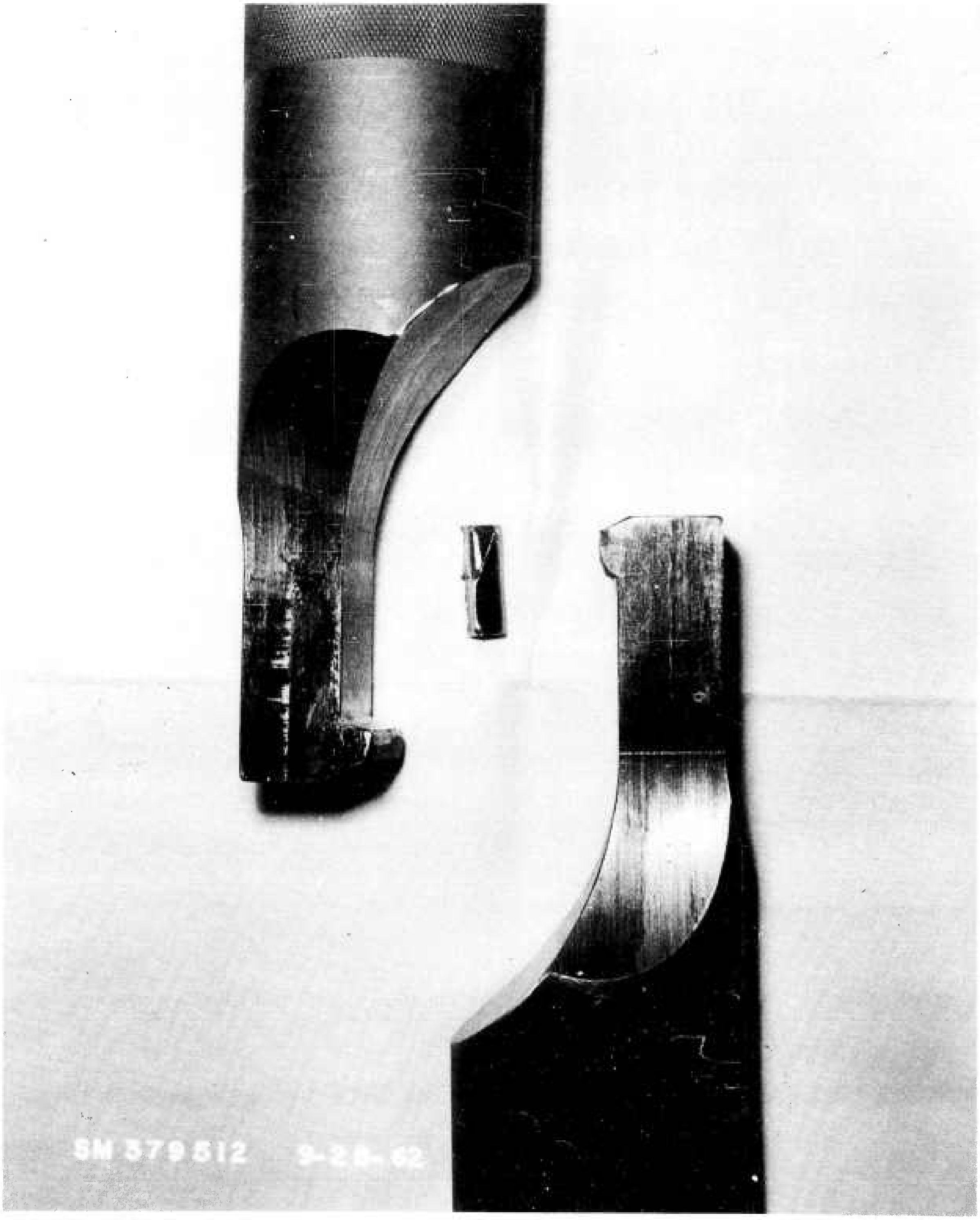
Tooling for construction of the 43-in. dia. subscale segments should be completed within three weeks. Two of the four 43-in. dia. "inner" joint rings (see Figure 22) are finished except for tapering. The other two inner joint rings are finished on their inside surfaces. Four 43-in. dia. "outer" segmented joint rings have been rough-machined and should be completed within three weeks. Clamps and bands necessary for testing assembled 43-in dia. segments are about 75 percent finished and should be completed within two weeks.

Two of the 43-in. dia. test closures are completed and the third will be finished within two weeks. In about three weeks, two of the closures will be assembled "back-to'back" and proof-tested. All test hardware for this test is completed.



CLAMP PULL TEST

**FIGURE 20**




CLAMPS (AFTER FAILURE)

**FIGURE 21**

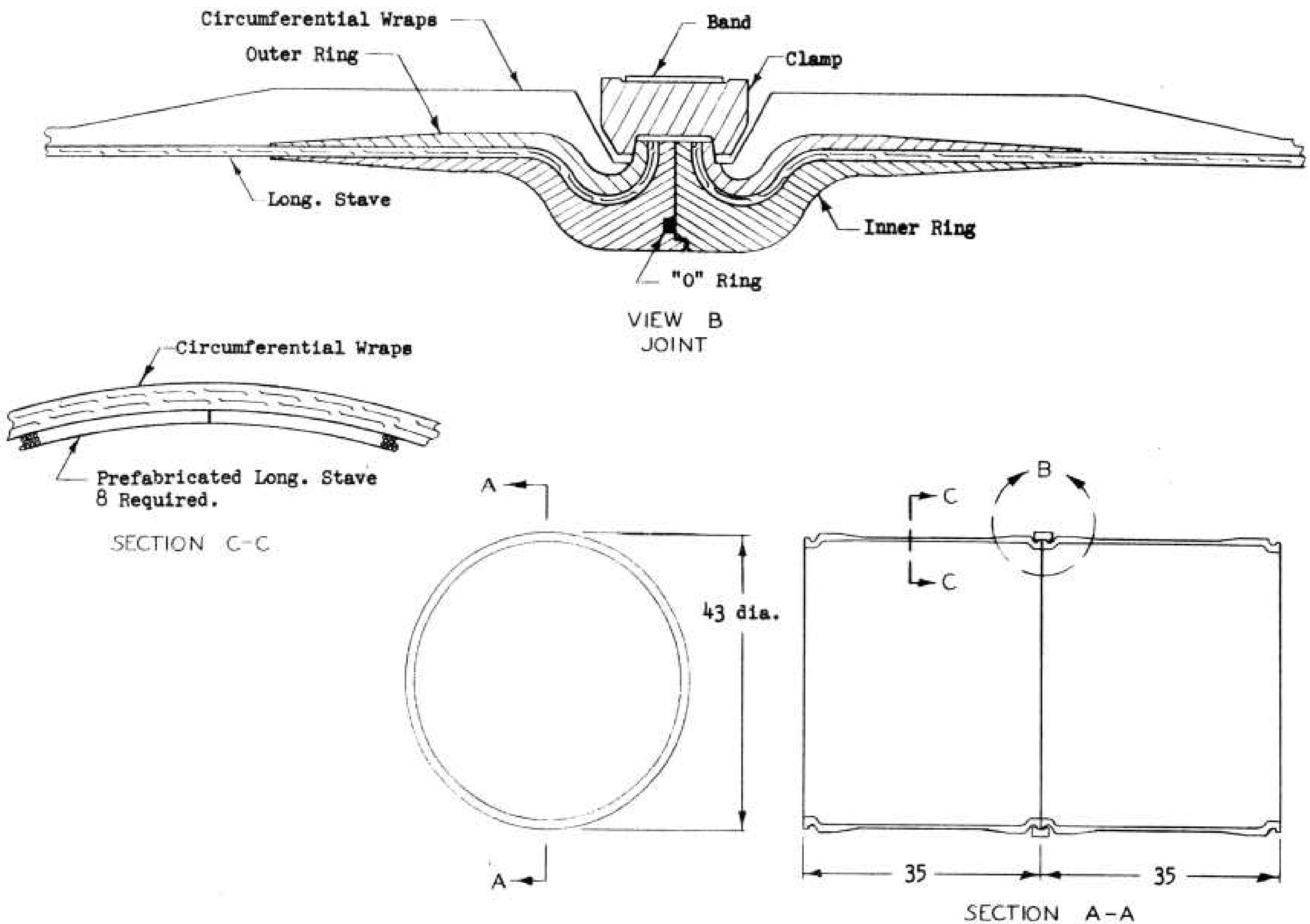



Figure 22. 43-In. Dia. Subscale Segmented Motor Case Design.

## 2.7 Outline of Work for Next Quarter

A brief description of work expected to be accomplished during the third quarter of segmented motor case development follows:

A. Bench Testing

The following work will be accomplished on the bench test program:

a. Five 6-in. dia. by 18-in. long segmented joint test specimens (Dwg. No. 1A35804) will be tested. (These tests will be in addition to the specimen already tested.)

b. Six 4-in. dia. by 6-in. long interlaminar shear, fiberglas-to-fiberglas, compression test specimens (Dwg. No. 1A35800) will be tested.

c. Six 16-in. dia. by 12-in. long compression test cylinders (Dwg. No. 1A35802) will be tested.

d. Six of the twelve 25-1/2-in. dia. by 20-in. long compression test cylinders (Dwg. No. 1A35803) will be fabricated. The study on the formulation of the inert propellant for these cylinders will be continued.

e. Three wedge shear test specimens (Dwg. No. 1A39826) will be tested.

Results from these tests will be analyzed and, in addition, analysis of tests previously completed will be continued. Any changes indicated by these analyses will be incorporated into the design of the 43-in. dia. segments.

B. Non-Scheduled Testing

Approximately 20 NOL rings will be tested to provide additional information on various pre-preg resin systems and cure cycles.

C. 43-In. Dia. Subscale Segments

The first pair of 43-in. dia. segments (including assembly clamps and bands) will be completed. The proof test closures will be proof-tested and then the first pair of 43-in. dia. segments will be burst-tested.

D. Scale-Up Study

The feasibility study of scaling the 43-in. dia. subscale segments to full-size 160-240-inch diameters will be continued.

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APPENDICES

## APPENDIX A [15]

## COMPUTER PROGRAM FOR THE DETERMINATION OF STRESSES IN LAP JOINTS

The following computer program (Fortan Program, F449) is now available for the determination of shear and direct stresses in lap joints.

TABLE OF CONTENTS

## I. FUNCTION:

To compute direct and shear stresses in a lap joint (see fig.1) from the following pair of simultaneous differential equations.

1) $A_2\sigma_2'' + 2A_2'\sigma_2' + (A_2'' - {}^{G}/_{E_2 b})\sigma_2 = -({}^{G}/_{E_1 b})\sigma_1$

2) $A_1\sigma_1'' + 2A_1'\sigma_1' + (A_1'' - {}^{G}/_{E_1 b})\sigma_1 = -({}^{G}/_{E_2 b})\sigma_2$

with $(\ )' \equiv {}^{d}/_{dx}(\ )$
where $\sigma_1$ and $\sigma_2$ are the unknowns. The A's are given as:

3) $A_1 = A_o(1 + \alpha x)^n$

4) $A_2 = B_o(1 + \beta x)^m$

where $A_o$, $B_o$, $\alpha$, $\beta$, n, m, are constants.

The boundary conditions are:

at $x = o$; $\sigma_2 = \sigma_{20}$, $\sigma_1 = o$

at $x = L$; $\sigma_2 = \sigma_{21}$, $\sigma_1 = \sigma_{10}$

The relationship of $\tau$, shear stress, to $\sigma_1$, $\sigma_2$, $A_1$, and $A_2$ is:

5) $\tau = A_1\sigma_1' + A_1'\sigma_1$

or 6) $\tau = -A_2\sigma_2' - A_2'\sigma_2$

## II. DEVELOPMENT OF EQUATIONS:

The above pair of simultaneous differential equations were reduced to a linear differential equation for evaluating $\sigma_1$ and $\sigma_2$.

Development of this equation is as follows:

Rewriting (1) and (2) above we have:

7) $A_2\sigma_2'' + 2A_2'\sigma_2' + A_2''\sigma_2 = {}^{G}/_{b}\left(\frac{\sigma_2}{E_2} - \frac{\sigma_1}{E_1}\right)$

8) $A_1\sigma_1'' + 2A_1'\sigma_1' + A_1''\sigma_1 = {}^{-G}/_{b}\left(\frac{\sigma_2}{E_2} - \frac{\sigma_1}{E_1}\right)$

II. DEVELOPMENT OF EQUATIONS: (Cont'd)

noting that:

9) $$\frac{d^2 (A_2\sigma_2)}{dx^2} = A_2\sigma_2'' + 2A_2'\sigma_2' + A_2''\sigma_2$$

10) $$\frac{d^2 (A_1\sigma_1)}{dx^2} = A_1\sigma_1'' + 2A_1'\sigma_1' + A_1''\sigma_1$$

We have by substituting (9) and (10) in (7) and (8) respectively.

11) $$\frac{d^2 (A_2\sigma_2)}{dx^2} = G/_b \left( \frac{\sigma_2}{E_2} - \frac{\sigma_1}{E_1} \right)$$

12) $$\frac{d^2 (A_1\sigma_1)}{dx^2} = -G/_b \left( \frac{\sigma_2}{E_2} - \frac{\sigma_1}{E_1} \right)$$

adding (11) and (12) we obtain:

13) $$\frac{d^2(A_2\sigma_2 + A_1\sigma_1)}{dx^2} = 0$$

integrating:

14) $$\frac{d(A_2\sigma_2 + A_1\sigma_1)}{dx} = C_1$$

15) $$A_2\sigma_2 + A_1\sigma_1 = C_1X + C_o$$

From the boundary conditions under "Function", the coefficients ($C_1$ and $C_o$) may be determined.

II. DEVELOPMENT OF EQUATIONS: (Cont'd)

16) $C_o = B_o \sigma_{20}$

17) $C_1 = (A_o(1+\alpha L)^n \sigma_{10} + B_o(1+\beta L)^m \sigma_{21} - B_o \sigma_{20}) / L$

Rewriting (15) we have:

18) $$\sigma_2 = \frac{C_1 X + C_o - A_1\sigma_1}{A_2}$$

Substituting (18) in (12) we have:

19) $$\frac{d^2(A_1\sigma_1)}{dx^2} = \frac{G}{b}\left[\frac{\sigma_1}{E_1} - \frac{1}{E_2}\left(\frac{C_1X + C_o - A_1\sigma_1}{A_2}\right)\right]$$

Letting:

20) $Y = A_1\sigma_1$

Differentiating:

21) $Y' = A_1\sigma_1' + A_1'\sigma_1 = \tau$

The boundary conditions for Y are:

at $X = 0$; $\quad Y = 0$

at $X = L$; $\quad Y = A_o(1+\alpha L)^n \sigma_{10}$

Substituting (20) in (19) and rewriting (19) we obtain the desired equation:

22) $$\frac{d^2Y}{dx^2} - \frac{G}{b}\left[\frac{1}{E_1A_1} + \frac{1}{E_2A_2}\right]Y = -\frac{G}{bE_2}\left[\frac{C_1X + C_o}{A_2}\right]$$

## III. METHOD OF SOLUTION:

Equation (22) above can be approximated by a difference equation and in solving the simultaneous set of algebraic equations resulting form the requirement that this equation be satisfied at each of a set of equally spaced points in the relevant interval. * The set of N simultaneous linear algebraic equations in $y_1$, $y_2$, ..., $y_N$ are of the form:

$$-2\left[1-{}^{5h^2}/_{12}\, f(X_1)\right]y(X_1) + \left[1 + {}^{h^2}/_{12}\, f(X_2)\right]y(X_2) = \frac{h^2}{12}K(X_1) - \left[1 + \frac{h^2}{12} f(X_o)\right]y(X_o)$$

$$\left[1 + {}^{h^2}/_{12}\, f(X_1)\right]y(X_1) - 2\left[1-{}^{5h^2}/_{12}\, f(X_2)\right]y(X_2) + \left[1 + {}^{h^2}/_{12}\, f(X_3)\right]y(X_3) = \frac{h^2}{12}K(X_1)$$

$$\left[1 + {}^{h^2}/_{12}\, f(X_2)\right]y(X_2) - 2\left[1-{}^{5h^2}/_{12}\, f(X_3)\right]y(X_3) + \left[1 + {}^{h^2}/_{12}\, f(X_4)\right]y(X_4) = \frac{h^2}{12}K(X_3)$$

$$\vdots \qquad\qquad \vdots \qquad\qquad \vdots$$

$$\left[1 + {}^{h^2}/_{12}\, f(X_{N-2})\right]y(X_{N-2}) - 2\left[1-{}^{5h^2}/_{12}\, f(X_{N-1})\right]y(X_{N-1}) + \left[1 + \frac{h^2}{12} f(X_N)\right]y(X_N) = \frac{h^2}{12}K(X_{N-1})$$

$$\left[1 + {}^{h^2}/_{12}\, f(X_{N-1})\right]y(X_{N-1}) - 2\left[1-{}^{5h^2}/_{12}\, f(X_N)\right]y(X_N) = \frac{h^2}{12}K(X_N) - \left[1 + {}^{h^2}/_{12}\, f(X_{N+1})\right]y(X_{N+1})$$

where from (22) above:

$$f(X_i) = -\frac{G}{b}\left[\frac{1}{E_1A_1(X_i)} + \frac{1}{E_2A_2(X_i)}\right]$$

$$k(X_i) = -\frac{G}{b}E_2\left[\frac{C_1X_i + C_o}{A_2(X_i)}\right] \qquad (i = 0, 1, 2, \ldots, N+1)$$

$$K(X_i) = k(X_i + h) + 10k(X_i) + k(X_i - h)$$

With $y(X_o)$ and $y(X_{N+1})$ the prescribed boundary conditions

* "Introduction to Numerical Analysis" by F. B. Hildebrand - 1956 McGraw-Hill - pp. 240-241.

Method of Solution: (Cont'd)

and $h + {}^{L}/_{N+1}$

The increment h, depends upon interval, L, such that:

| | |
|---|---|
| $0 < L \leq 1$ | $h = .001$ |
| $1 < L \leq 2$ | $h = L/1000$ |
| $2 < L \leq 8$ | $h = L/2000$ |
| $L > 8$ | $h = L/4000$ |

$\sigma_1$ and $\sigma_2$ are computed from (20) and (18) respectively.

$A_1$ and $A_2$ are computed from (3) and (4) respectively.

By representing the function, Y, with an interpolation formula employing differences and then differentiating this formula, the value $\tau$ can be computed. (See equation (21) above.) The following formulas, which are the first derivatives of Newton's Formula I, Stirlings Formula, and Newton's Formula II respectively, are used to evaluate $\tau$.

$$\tau_o = ( -25y_o + 48y_1 - 36y_2 + 16y_3 - 3y_4) /12h$$

$$\tau_i = ( y_{i+3} - 9y_{i+2} + 45y_{i+1} - 45y_{i-1} + 9y_{i-2} - y_{i-3}) /60h$$

where $i = 1, 2, 3, \ldots, N$

$$\tau_{N+1} = (25y_{N+1} - 48y_N + 36y_{N-1} - 16y_{N-2} + 3y_{N-3}) /12h$$

## IV. DEFINITION OF SYMBOLS:

| Symbol | Description | Units |
|---|---|---|
| $A_o$ | Total area of section 1 at x = 0 | $inches^2$ |
| $A_1$ | Total area of section 1 at any point x | $inches^2$ |
| $A_2$ | Total area of section 2 at any point x | $inches^2$ |
| $\alpha$ | Coefficient describing the taper of section 1 | 1/inches |
| $\beta$ | Coefficient describing the taper of section 2 | 1/inches |
| $B_o$ | Total area of section 2 at x = 0 | $inches^2$ |
| b | Thickness of glue line | inches |
| $E_1$ | Modulus of elasticity of section 1 | psi |
| $E_2$ | Modulus of elasticity of section 2 | psi |
| G | Shear modulus of glue | psi |
| L | Length of lap joint | inches |
| m | Exponent describing the taper of section 2 | - |
| n | Exponent describing the taper of section 1 | - |
| $\sigma_1$ | Direct Stresses | psi |
| $\sigma_{10}$ | " " | psi |
| $\sigma_2$ | " " | psi |
| $\sigma_{20}$ | " " | psi |
| $\sigma_{21}$ | " " | psi |
| $\tau$ | Shear " | psi |

V. STORAGE USED:

| Symbol | Dimension | Description |
|---|---|---|
| T | 8002 | T(8001) - T(4001) are allowed for storage of solution. All other T storage is temporary storage. |
| A | 4000 | Coefficients of N simultaneous difference equations. |
| B | 4000 | Coefficients of N simultaneous difference equations. |
| C | 4000 | Coefficients of N simultaneous difference equations. |
| D | 4000 | Coefficients of N simultaneous difference equations. |
| DD | 14 | Data Storage |
| RR | 14 | Reference run data storage |
| F | 11 | Temporary Storage |

## VI. INPUT:

Instructions for filling out the load sheet are as follows:

The reference run * and case number must be filled in on each load sheet.

A value must be entered for every quantity listed on the load sheet.

The decimal point is assumed to be left justified in the value field and the following relationship holds:

$$\text{Value X } 10^{E} = \text{Quantity}$$

*Zero's are entered in the reference run field if the reference run capability, which is available in this program, is not used.

## VII. INPUT RESTRICTIONS:

For $L < 1.$ enter only three significant digits.

## VIII. OUTPUT:

The output will consist of values for areas, $A_1$ and $A_2$, direct stresses, $\sigma_1$ and $\sigma_2$, and shear stresses, $\tau$, for $x = 0, \Delta x, 2\Delta x, 3\Delta x, \ldots, L$. The number of values output will depend of the the length of the lap joint, L, such that:

| Length of Lap Joint | Values Output |
|---|---|
| $0 < L \leq 1.$ * | $0 < V \leq 50$ |
| $1. < L \leq 2.$ | 21 |
| $2. < L \leq 8.$ | 41 |
| $L > 8.$ | 81 |

Reference should be made to the output from the test case for the print format of the above stresses.

*The increment, $\Delta x = .02$, is used in this interval however the last increment may vary from .02 to .039.

IX. FIGURES

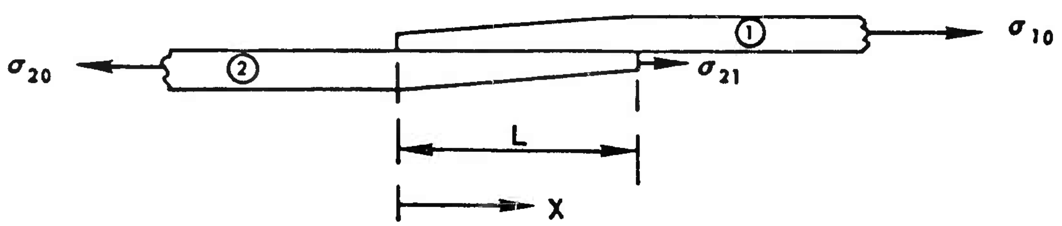
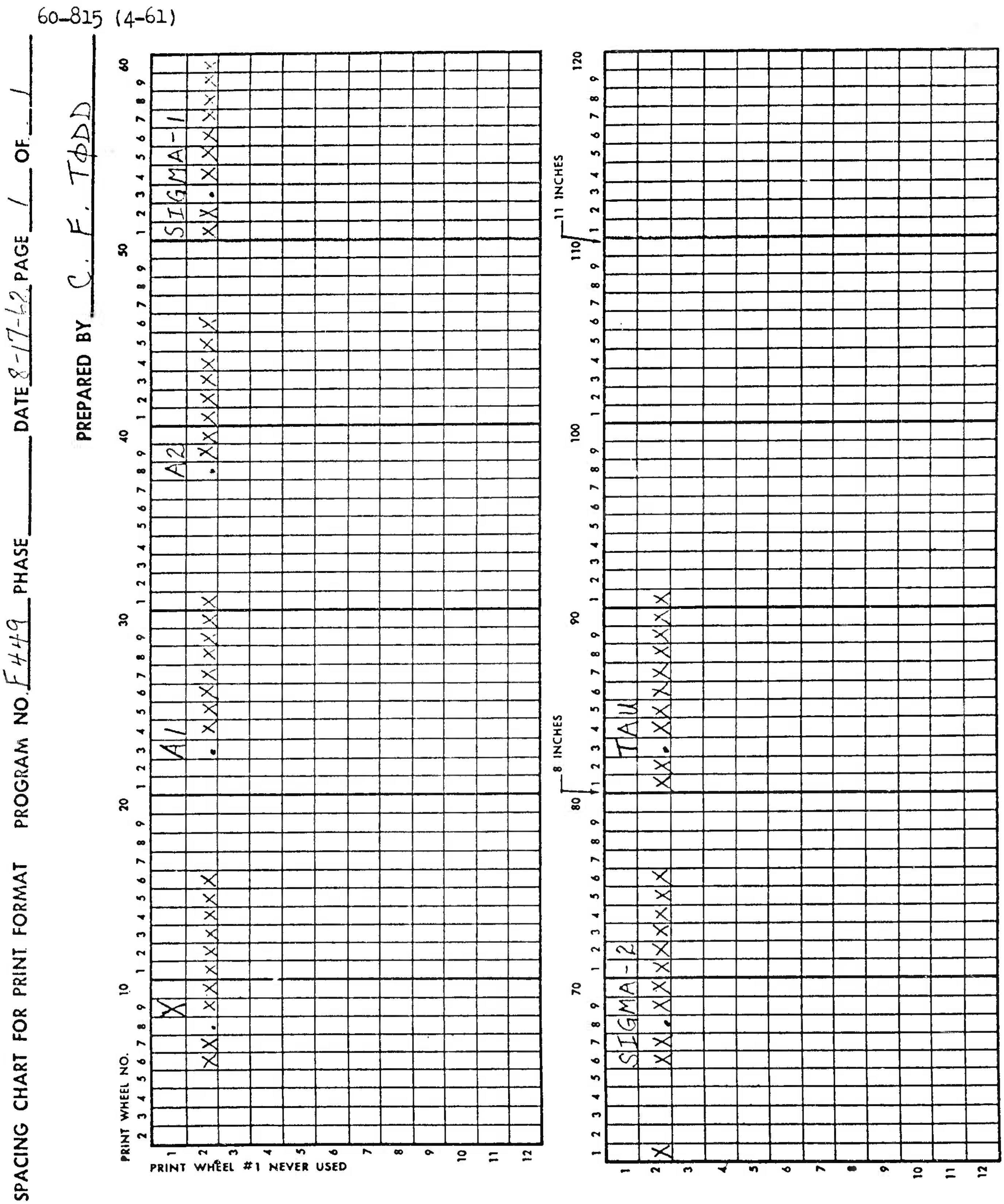



FIGURE 1




X. OUTPUT FORMAT

F449
SHEAR STRESSES IN LAP JOINTS

7090 DATA LOAD SHEET

DATA INPUT 1 PAGE 1 OF 1

PREPARED BY C. F. TODD DATE 8-25-62

ENGINEERING VALUE × $10^E$ = QUANTITY

MUST BE FILLED IN FOR PROPER PROCESSING

| 66 | 68 69 70 71 | 73 74 | 75 |
|---|---|---|---|
| BO | RR | CASE | |
| | 00 | 010 | |

TEST CASE

| DESCRIPTION | QUAN | LOC | ± | VALUE | ± | E |
|---|---|---|---|---|---|---|
| SHEAR MODULUS OF GLUE | G | 00001 | | 1.26 | | 06 |
| MODULUS OF ELASTICITY OF SECTION 1 | $E_1$ | 00002 | | 30. | | 09 |
| MODULUS OF ELASTICITY OF SECTION 2 | $E_2$ | 00003 | | 30. | | 09 |
| THICKNESS OF GLUE LINE | b | 00004 | | 1 | - | 01 |
| AREA OF SECTION 1 @ X = 0 | $A_0$ | 00005 | | 1.25 | | 00 |
| AREA OF SECTION 2 @ X = 0 | $B_0$ | 00006 | | 1.25 | | 00 |
| COEFFICIENT DESCRIBING THE TAPER OF SECTION 1 | $\alpha$ | 00007 | | 0. | | 00 |
| COEFFICIENT DESCRIBING THE TAPER OF SECTION 2 | $\beta$ | 00008 | | 1.439 | | 00 |
| STRESS IN SECTION 1 @ X = L | $\sigma_{10}$ | 00009 | | 7.52 | | 01 |
| STRESS IN SECTION 2 @ X = 0 | $\sigma_{20}$ | 00010 | | 8 | | 01 |
| LENGTH OF LAP JOINT | L | 00011 | | 1.91 | | 01 |
| EXPONENT DESCRIBING THE TAPER OF SECTION 2 | m | 00012 | - | 1.313 | | 02 |
| EXPONENT DESCRIBING THE TAPER OF SECTION 1 | n | 00013 | | 1 | | 01 |
| STRESS IN SECTION 2 @ X = L | $\sigma_{21}$ | 00014 | | 8 | | 01 |

KEYPUNCH: STANDARD INPUT 1

XI. SAMPLE PROBLEM INPUT.

REFERENCE RUN NO. 00 CASE NO. 010

| X | A1 | A2 | SIGMA-1 | SIGMA-2 | TAU |
|---|---|---|---|---|---|
| -0. | 0.12500000 | 0.12499997 | 0. | 8.00000179 | 1.82481989 |
| 0.09549999 | 0.12500000 | 0.10449133 | 1.27821453 | 8.03210330 | 1.52961412 |
| 0.19099999 | 0.12500000 | 0.08755854 | 2.34897217 | 8.04607415 | 1.28047739 |
| 0.28649999 | 0.12500000 | 0.07354224 | 3.24472189 | 8.04429984 | 1.07041745 |
| 0.38199999 | 0.12500000 | 0.06191111 | 3.99303934 | 8.02954769 | 0.89363561 |
| 0.47749998 | 0.12500000 | 0.05223577 | 4.61736304 | 8.00485587 | 0.74503738 |
| 0.57299998 | 0.12500000 | 0.04416825 | 5.13756722 | 7.97351754 | 0.62044969 |
| 0.66849998 | 0.12500000 | 0.03742585 | 5.57060266 | 7.93860084 | 0.51628934 |
| 0.76399997 | 0.12500000 | 0.03177821 | 5.93085486 | 7.90288013 | 0.42942689 |
| 0.85949996 | 0.12500000 | 0.02703718 | 6.23047578 | 7.86874962 | 0.35716503 |
| 0.95499995 | 0.12500000 | 0.02304970 | 6.47971386 | 7.83801806 | 0.29716153 |
| 1.05049995 | 0.12500000 | 0.01968629 | 6.68714994 | 7.81196755 | 0.24743014 |
| 1.14599994 | 0.12500000 | 0.01684589 | 6.85997433 | 7.79107654 | 0.20628310 |
| 1.24149993 | 0.12500000 | 0.01444168 | 7.00409335 | 7.77574241 | 0.17210841 |
| 1.33699992 | 0.12500000 | 0.01240271 | 7.12443221 | 7.76559556 | 0.14376486 |
| 1.43249992 | 0.12500000 | 0.01067021 | 7.22501665 | 7.76024103 | 0.12023254 |
| 1.52799991 | 0.12500000 | 0.00919539 | 7.30907255 | 7.76024944 | 0.10037466 |
| 1.62349990 | 0.12500000 | 0.00793763 | 7.37916899 | 7.76787651 | 0.08353537 |
| 1.71899989 | 0.12500000 | 0.00686307 | 7.43722600 | 7.79000670 | 0.06871743 |
| 1.81449988 | 0.12500000 | 0.00594345 | 7.48432016 | 7.84706092 | 0.05454007 |
| 1.91000000 | 0.12500000 | 0.00515509 | 7.51999992 | 7.99999861 | 0.03811238 |

XII. SAMPLE PROBLEM OUTPUT.

## APPENDIX B [11]

## STRENGTH ANALYSIS

The expression for Z used in Appendix A (Strength Analysis) of Quarterly Progress Report No. 1 [14] is incorrect. The following strength analysis is identical to the one appearing in Appendix A of Report No. 1 except the correct expression for Z is used.

### Loads

The 43-in. dia. segmented motor case represents a subscale version of the 160-in. dia. motor case. The full-size (160 in. dia.) motor case has internal pressure, external pressure; and axial, lateral, and bending loads acting on it. However, the design of the 43-in. dia. motor case is based primarily on a chamber pressure of 2000 psi. (Reference 1.) Being a proof pressure, this must be considered as a limit load.

The axial load per inch of circumference is:

$$N_x = \frac{p\ R}{2}$$

$R = 21.7$ in. (mean) — Reference 2

$N_x = \dfrac{2000 \times 21.7}{2} = 21{,}700$ lb/in. — Tension (Limit)

$N_x = 1.25 \times 21{,}700 = 27{,}125$ lb/in. — (Ultimate)

The hoop load per inch of length is:

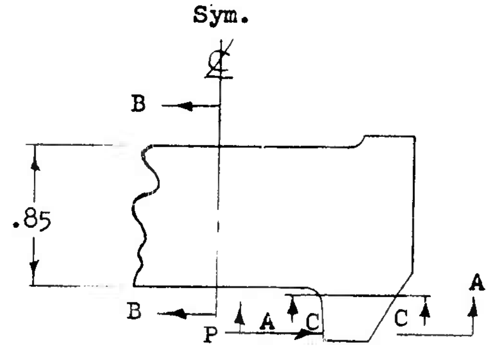
$N_y = p\ R = 43{,}400$ lb/in. — Tension (Limit)

$N_y = 1.25 \times 43{,}400 = 54{,}250$ lb/in. — (Ultimate)

Analysis of Clamp

Shear of the clamp through

Section A-A




$A = 1.0 \times 0.30 = 0.3 \text{ in.}^2$

$\tau = \frac{P}{A} = \frac{27{,}125 \times 1.0}{0.3}$

$= 90{,}400$ psi.

$F_{su} = 109{,}000$ psi

Ref. 3, Table 2.2.2.0 (b)

$\text{M.S.} = \frac{109{,}000}{90{,}400} - 1 = \underline{.21}$

Bending and tension at Section B-B

$Z = \frac{I}{c} = \frac{bh^2}{b} = \frac{1.0\ (.85)^2}{6} = 0.1203 \text{ in.}^3$

$I = \frac{bh^3}{12} = \frac{1.0\ (.85)^3}{12} = 0.0511 \text{ in.}^4$

$A = 1.0 \times 0.85 = 0.85 \text{ in.}^2$

$M = 27{,}125 \times 0.66 = 17{,}900$ in. lb.

$\sigma = \frac{M}{Z} + \frac{P}{A} = \frac{17{,}900}{0.1203} + \frac{27{,}125}{0.85} = 148{,}700 + 31{,}900$

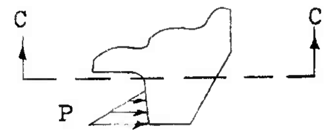
$\sigma = 180{,}600$ psi

$F_{tu} = 180{,}000$ psi

$\text{M.S.} = \frac{180{,}000}{180{,}600} - 1 = \underline{\underline{.00}}$

Bending of the lip through Section C-C

Assuming a uniformly varying load as shown




$M = 27{,}125 \times 0.195 = 5280$ in.-#

$$Z = \frac{1.0\,(0.45)^2}{6} = .0338 \text{ in}^3$$

Fillet Radius = r = .07 in.

Plate thickness = t = .45 in.

$$\frac{r}{t} = \frac{.07}{.45} = .156$$

$K_T = 1.60$ Ref. 4, page 223

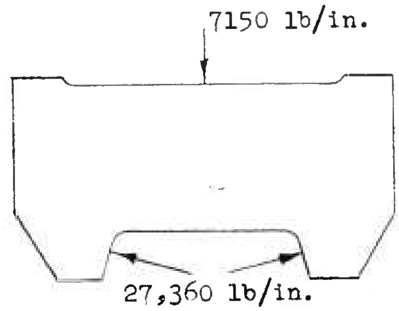
$$\sigma = 1.60\,\frac{5280}{.0338} = 249{,}000 \text{ psi.}$$

$F_{bu} = 250{,}000$ psi. (based on yield) Ref. 5, Section 93.31

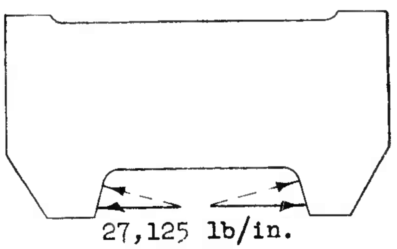
$$\text{M.S.} = \frac{250{,}000}{249{,}000} - 1 = .00$$

Analysis of Band

The 7-1/2° angle between the mating surfaces of the clamp and the hook imposes a radial force at these surfaces. It is assumed that this radial force is reacted by friction between the surfaces.




No Friction




With Friction

The static coefficient of hard steel on hard steel is given by Reference 6 on pages 218 and 219 as

| | | |
|---|---|---|
| Dry | - | 0.78 |
| Oxide Film | - | 0.27 |
| Greasy | - | 0.0052 to 0.23 |

The sliding friction coefficient is

| | | |
|---|---|---|
| Dry | - | 0.42 |
| Greasy | - | 0.029 to 0.12 |

$$\tan 7\text{-}1/2^{\circ} = 0.1317$$

The sliding coefficient is more applicable because of the relative circumferential motion between the segmented clamp and the one-piece hook.

Relative motion between the band and the clamp segments can be minimized by adding a lubricating film between the two. It is assumed that a film of Teflon separates the two and reduces the load to zero.

Then the strap is designed only to take hoop tension loads due to expansion of the joint in the radial direction. Material of the strap is half hard 301 stainless steel.

Change of radius of the joint is

$$\Delta R = \frac{R^2 p}{Et} \left(1 - \frac{\nu}{2}\right)$$

$$p = 2000 \times 1.25 = 2500 \text{ psi}$$

$R = 21.8$ in.

$t = 1.5$ in.

$\nu = 0.3$

$E = 30 \times 10^6$ psi

$$\Delta R = \frac{(21.8)^2\ 2500}{30 \times 10^6 \times 1.5} \left(1 - \frac{0.3}{2}\right) = .0225 \text{ in.}$$

Stress in the strap

$$\sigma = \frac{E'\ \Delta R}{R'}$$

$E' = 26{,}000{,}000$ psi — Reference 3, Table 2.2.3.0 (b)

$R' = 22.8$ in.

$$\sigma = \frac{26 \times 10^6 \times .0025}{22.8} = 25{,}700 \text{ psi}$$

$F_{t_u} = 150{,}000$ psi — Reference 3, Table 2.2.3.0 (b)

Efficiency of spotwelded sheet = .95 — Reference 3, Fig. 8.1.2.3.1 (b)

$$\text{M.S.} = \frac{150{,}000 \times .95}{25{,}700} - 1 = 4.54$$

The strap is attached with seven spotwelds.

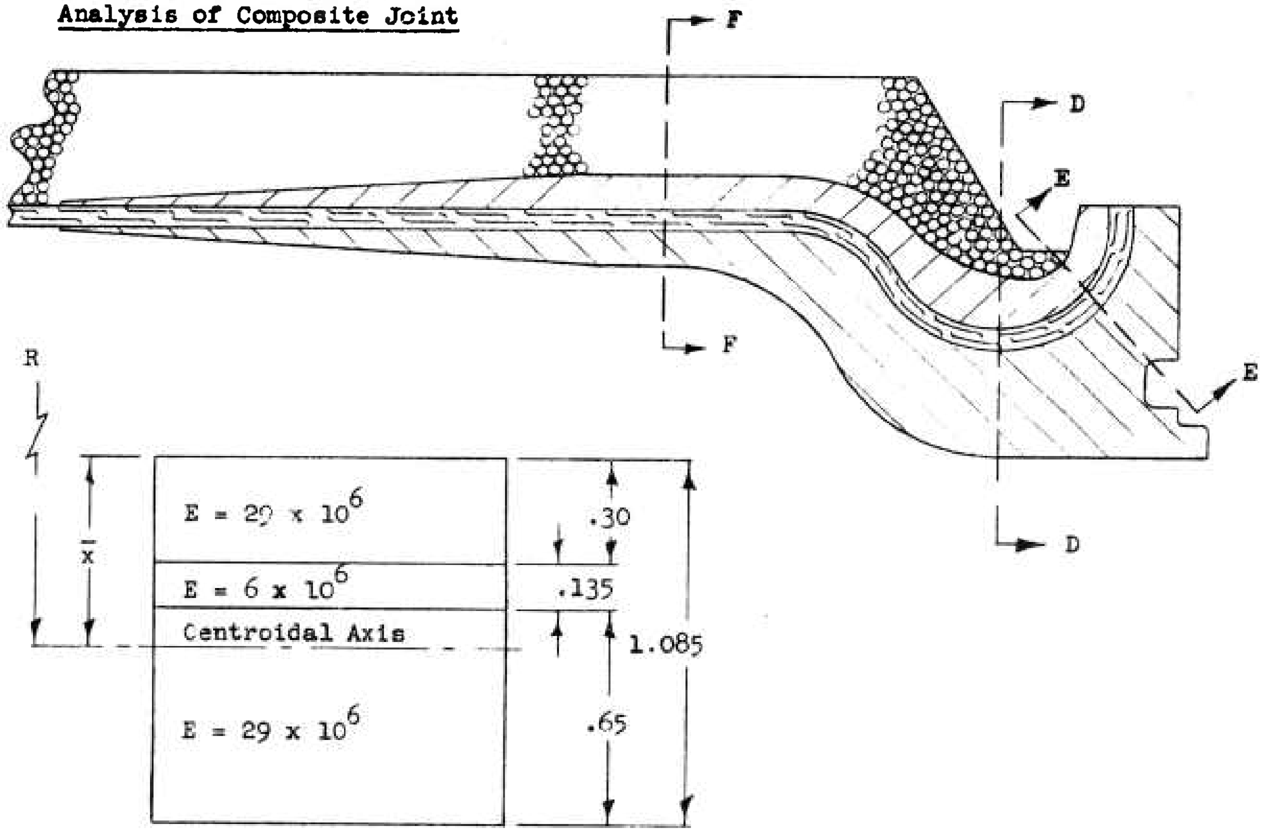
$P = \sigma A = 25{,}700 \times 1.5 \times .025 = 964$ lbs.

$P_{ALLOW} = 7 \times 580 = 4060$ lbs. — Ref. 3, Table 8.1.2.3 (a)

$$\text{M.S.} = \frac{4060}{964} - 1 = \underline{\underline{3.21}}$$

Other parts are satisfactory by comparison.

**Analysis of Composite Joint**




Section D-D

$$\bar{X} = \frac{(29 \times .30 \times .150)+(6 \times .135 \times .368)+(29 \times .65 \times 76)}{(29 \times .30)+(6 \times .135)+(29 \times .65)}$$

$$\bar{X} = \frac{1.306 + .298 + 14.330}{8.70 + 0.81 + 18.82}$$

$$\bar{X} = \frac{15.944}{28.33}$$

$\bar{X}$ = .563 in.

R = 0.89"

$$\frac{E_2}{E_1}\ t_2 = \frac{6 \times 10^6}{29 \times 10^6}\ \text{x}.135 = .028''$$

$$Z = -1 + \frac{R}{t_1 + t_3 + \frac{E_2}{E_1} \; t_2} \left\{ \log (R + t_1 + t_2 + t_3 - \bar{X}) \right.$$

$$+ (\frac{E_2}{E_1} - 1) \log_e (R + t_1 + t_2 - \bar{X})$$

$$\left. + (1 - \frac{E_2}{E_1}) \log_e (R + t_1 - \bar{X}) - \log_e (R - \bar{X}) \right\}$$

$$Z = -1 + \frac{.89}{.65 + .30 + .028} \left\{ \log (.89 + 1.085 - .563) \right.$$

$$+ (.207 - 1) \log_e (.89 + .30 + .135 - .563)$$

$$\left. + (1 - .207) \log_e (.89 + .30 - .563) - \log_e (.89 - .563) \right\}$$

$$Z = -1 + .911 \left[ .3453 + .793 (- .4670 + .272) + 1.118 \right]$$

$$Z = -1 + 1.191 = .191$$

The maximum bending moment in the hook (section D-D) can be obtained using the analysis given in Appendix E of Reference 14. At section D-D the expression for bending moment is given as

$$M = \frac{EI}{R^2} \left\{ A_1 \; A_8 + A_2 \; A_7 - 2 \, \alpha \, \beta \, (A_1 + A_3 \; A_7) \right\} \frac{P}{\mathcal{J}}$$

where the various parameters are defined in the Appendix. Since the curved joint has a continuous inner ring and a hoop overwrap, these essentially constitute an elastic foundation, the modulus of which is given as:

$$K = \left[\frac{E_2\ t_2}{a^2} + \frac{E_1\ t_3}{a^2}\right]$$

Evaluating k,

$$k = \frac{6 \times 10^6 \times .3}{(21.7)^2} + \frac{29 \times 10^6 \times .65}{(21.7)^2}$$

$$k = 4.39 \times 10^4 \text{ lb/in}^3$$

The flexural rigidity EI at the composite section is

$$EI = \frac{29 \times 10^6\ (.30)^3}{12} + 29 \times 10^6 \times .30\ (.413)^2 + \frac{6 \times 10^6\ (.135)^3}{12}$$

$$+ 6 \times 10^6 \times .135\ (.196)^2 + \frac{29 \times 10^6 \times (.65)^3}{12} + 29 \times 10^6 \times .65\ (.197)^2$$

$$EI = 2.972 \times 10^6 \text{ lb-in}^2$$

The value of $\eta$ is

$$\eta = \sqrt{\frac{R^4\ k}{EI} + 1} = \sqrt{\frac{(.89)^4 \times 4.39 \times 10^4}{2.972 \times 10^6} + 1} = 1.004625$$

The values of $\alpha$ and $\beta$ are

$$\alpha = \sqrt{\frac{\eta - 1}{2}} = \sqrt{\frac{1.004625 - 1}{2}} = .04809$$

$$\beta = \sqrt{\frac{\eta + 1}{2}} = \sqrt{\frac{1.004625 + 1}{2}} = 1.001156$$

It will be assumed that the joint constitutes half of the ring so that

$$\gamma = 90^{\circ} = \pi/2$$

then

$$\alpha \frac{\pi}{2} = .07554$$

$$\beta \frac{\pi}{2} = 1.57262$$

$$Y_{10} = \cosh \alpha \frac{\pi}{2} \cos \beta \frac{\pi}{2} = (1.00283)(-\ .00182) = -\ .001825$$

$$Y_{20} = \sinh \alpha \frac{\pi}{2} \sin \beta \frac{\pi}{2} = (.07560)(1.000) = .07560$$

$$Y_{30} = \cosh \alpha \frac{\pi}{2} \sin \beta \frac{\pi}{2} = (1.00283)(1.000) = 1.00283$$

$$Y_{40} = \sinh \alpha \frac{\pi}{2} \cos \beta \frac{\pi}{2} = (.07560)(-\ .00182) = -\ .000138$$

Using the above values it is now possible to evaluate the A's.

$$A_1 = .030686 \times 10^6 \qquad A_5 = -\ .407520 \times 10^6$$

$$A_2 = .000741 \times 10^6 \qquad A_6 = .0$$

$$A_3 = .039071 \times 10^6 \qquad A_7 = .007280$$

$$A_4 = -\ .019520 \times 10^6 \qquad A_8 = -\ .000176$$

Evaluating $\mathscr{D}$

$$\mathscr{D} = (-\ .19520 \times 10^6) \left[(.039071 \times 10^6)(-\ .000176) - .000741 \times 10^6\right]$$

$$+ (-\ .407520 \times 10^6) \left[(.039071 \times 10^6)(.007280) + .030686 \times 10^6)\right]$$

$$\mathcal{D} = 10^6 \left[14.600 - 12{,}621.1 \quad = - 12.617 \times 10^9\right]$$

Evaluating M/EI

$$\frac{M}{EI} = \frac{1}{(.89)^2} \left[(.030686 \times 10^6)(-.000176) + (.000741 \times 10^6)(.007280)\right]$$

$$- (.09629) \left[.030686 \times 10^6 + (.039071 \times 10^6)(.007280)\right] \frac{P}{\mathcal{D}}$$

$$\frac{M}{EI} = - 3764.8 \frac{P}{\mathcal{D}}$$

$$\frac{M}{EI} = \frac{- 3764.8 \text{ P}}{- 12.617 \times 10^9} = 298.39 \text{ P} \times 10^{-9}$$

The maximum bending stress is given as

$$\sigma = K_1 \frac{M}{EI} \; y_1 \; E_1$$

where $E_1$ is the modulus of elasticity of a fiber at a distance $y_1$ from the centroid, and K is the factor which takes into account the nonlinear stress distribution (curved beam effect) across the section,

$$K_1 = \frac{\left[1 + \frac{1}{Z} \left(\frac{y}{R + y}\right)\right] EI}{y_1 \; E_1 \; R \; A}$$

Substituting the values for various parameters yields (note that for inner surface, y is negative)

$$K_1 = \frac{\left[1 + \frac{1}{.191} \left(\frac{- .563}{.89 - .563}\right)\right] \; 2.972 \times 10^6}{- .563 \; (29 \times 10^6)(.89)(.978)}$$

$$K_1 = 1.68$$

Finally the stress due to bending is

$$\sigma_B = (.168)(298.39 \times 10^{-9})(.563)(29 \times 10^6) P$$

$$\sigma_B = 8.2 P$$

The direct stress at any section is given as

$$\sigma_i = \frac{PE_i}{E_1 t_1 + E_2 t_2 + E_1 t_3} \qquad (i = 1, 2, 3)$$

In the upper portion of the hook

$$\sigma_1 = \frac{29 \times 10^6 P}{10^6 \left[29 \times .30 + 6 \times .135 + 39 \times .65\right]} = \frac{29 P}{28.36}$$

$$\sigma_1 = 1.023 P$$

Hence the total maximum tensile stress in the hook is

$$\sigma_T = 8.2P + 1.023P = 9.223P$$

Since P = 27,125 lbs/in

$$\sigma_T = 9.223 (27,125)$$

$$\sigma_T = 250,000 \text{ psi (Tension)}$$

$$F_{BU} = 250,000$$

$$M.S. = \frac{250,000}{250,000} - 1 = 0.00$$

For the lower portion of the hook, i.e., y = .522, the value of K is

$$K_3 = \frac{\left[1 + \frac{1}{.191}\left(\frac{.522}{.89 + .522}\right)\right] 2.972 \times 10^6}{.522\,(29 \times 10^6)(.89)(.978)}$$

$$K_3 = .66$$

while the bending stress is

$$\sigma_B = - (.66)(298.39 \times 10^{-9})(.522)(29 \times 10^6)\ P$$

$$\sigma_B = - 2.99\ P$$

For section (3) the direct stress is

$$\sigma_B = 1.022\ P$$

Hence the total stress is

$$\sigma_T = -2.99\ P + 1.022\ P = - 1.968\ P,$$

or finally,

$$\sigma_T = - 1.968 \times 27{,}125 = - 53{,}400 \text{ psi (Compression)}$$

The maximum bending stress in the plastic stave is

$$\sigma_B = K_2 \left(\frac{M}{EI}\right)(y_2)\ E_2$$

where

$$K_2 = \frac{\left[1 + \frac{1}{Z}\left(\frac{y_2}{R + y_2}\right)\right]EI}{y_2\ E_2\ R\ A} = \frac{\left[1 + \frac{1}{.191}\left(\frac{-\ .263}{.89\ -\ .263}\right)\right]\ 2.972 \times 10^6}{-\ .263\ (6 \times 10^6)\ (.89)\ (.978)}$$

$$K_2 = 2.598$$

The bending stress is

$$\sigma_B = (2.598)(298.39 \times 10^{-9})(.263)(6 \times 10^6)$$

$$\sigma_B = 1.222 \text{ P}$$

The direct stress for the stave is

$$\sigma_2 = \frac{6 \times 10^6 \text{P}}{28.36 \times 10^6} = .212 \text{ P}$$

Hence the total maximum tensile stress in the stave is

$$\sigma_T = 1.222 \text{ P} + .212 \text{ P} = 1.434\text{P}$$

$$\sigma_T = 1.434 \times 27{,}125 = 38{,}900 \text{ psi (Tension)}$$

For the stave

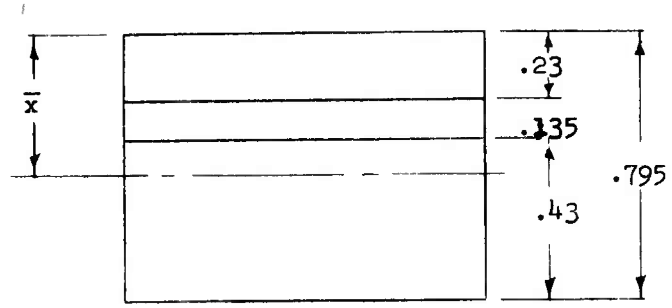
$$F_{TU} = 180{,}000$$

hence

$$\text{M.S.} = \frac{180{,}000}{38{,}900} - 1 = 3.63$$

Section E-E

Pressure of the O-Ring groove at section E-E requires evaluation of stresses at that section.




Section E-E

$$\bar{X} = \frac{(29 \times 10^6 \times .23 \times .115) + (6 \times 10^6 \times .135 \times .298) + (29 \times 10^6 \times .43 \times .580)}{(29 \times 10^6 \times .23) + (6 \times 10^6 \times .135) + (29 \times 10^6 \times .43)}$$

$$\bar{X} = \frac{8.29}{19.94} = 0.416 \text{ in.}$$

For this case

$$R \approx .80$$

$$\frac{E_2}{E_1} t_2 = .028$$

$$Z = -1 + \frac{.80}{.43 + .23 + .028} \Big[ \log_e (.80 + .23 + .135 + .43 - .416)$$

$$+ (.207 - 1) \log_e (.80 - .416 + .23 + .135)$$

$$+ (1 - .207) \log_e (.80 - .416 + .23) - \log_e (.80 - .416) \Big]$$

$$Z = -1 + 1.120 = .120$$

Examination of the previous calculation shows that the effect of hoop curvature for the cylinder of this size is small. Moreover, treating the ring as a curved beam gives conservative results, i.e., somewhat lower stresses are obtained if the hoop curvature is taken into account. For this reason the stresses at section E-E will be computed on the basis of curved beam theory. For this case the vertical component, $R_V$, of R is

$$R_V = R \sin 45^\circ = .80 \times .707 = .566$$

while

$$M = .566 \times 27{,}125 = 15{,}380 \text{ in-lb/in.}$$

The flexural rigidity of section E-E is

$$EI = \frac{29 \times 10^6 \times (.23)^3}{12} + 29 \times 10^6 \times .23\,(.301)^2 + \frac{6 \times 10^6\,(.135)^3}{12}$$

$$+ 6 \times 10^6 \times .135\,(.118)^2 + \frac{29 \times 10^6 \times (.43)^3}{12} + 29 \times 10^6 \times .43\,(.164)^2$$

$$EI = 1.174 \times 10^6 \text{ lb-in}^2$$

The value of K is

$$K = \frac{\left[1 + \frac{1}{.120}\left(\frac{+\,.379}{.80 + .379}\right)\right] 1.174 \times 10^6}{.379\,(29 \times 10^6)(.80)(.688)}$$

$$K = .716$$

The bending stress is

$$\sigma_B = (.716)\,\frac{15,380}{1.174 \times 10^6}\,(.379)(29 \times 10^6)$$

$$\sigma_B = 103,000 \text{ psi (compression)}$$

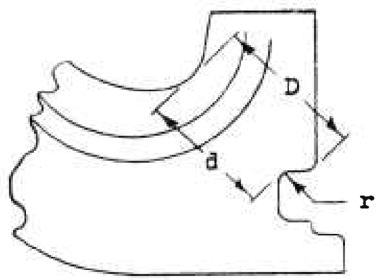
The direct stress is

$$\sigma_B = \frac{(27,125) \sin 45^\circ \, (29 \times 10^6)}{(29 \times 10^6)(.23) + (29 \times 10^6)(.43) + (6 \times 10^6)(.135)} = 27,900 \text{ psi}$$

Hence the total stress at section E-E is (at O-ring)

$$\sigma_T = -\,103,000 + 27,900 = -\,75,100 \text{ psi (compression)}$$

If the O-ring groove is treated as a fillet, the approximate value of factor $K_T$ can be obtained from Ref. 9 (p. 69).




$$\frac{r}{d} = \frac{.05}{.795} = .063$$

$$\frac{D}{d} = \frac{.90}{.795} = 1.130$$

$$K_T = 1.85^*$$

Hence the stress at the fillet is

$$T = 1.85 \times 75,100 = 139,000 \text{ psi}$$

$$F_{bu} = 250,000$$

*Note: A more exact value of $K_T$ is being determined using photoelasticity.

Hence

$$M.S. = \frac{250,000}{139,000} - 1 = .8$$

Analysis of Staves

In the center of each segment, the staves resist the longitudinal loads.

$P = 27,125$ lb/in.

$t = 0.135$ in.

$$\sigma = \frac{P}{A} = \frac{27,125}{1.0 \times .135} = 200,925 \text{ psi}$$

$$F_{tu} = 200,000 \text{ psi}$$

$$M.S. = \frac{200,000}{200,925} - 1 = .00$$

Analysis of Hoop Wraps

In the center of each segment, the hoop wraps resist the hoop loads because there is no helix angle.

$P = 54,250$ lbs.

$t = 0.240$ in. (Ref. 2)

$$\sigma = \frac{P}{A} = \frac{54,250}{1.0 \times .240} = 226,000 \text{ psi.}$$

$$F_{tu} = 220,000 \text{ psi}$$

$$M.S. = \frac{220,000}{226,000} - 1 = -.02$$

## APPENDIX C

## DISTRIBUTION LIST

| | |
|---|---|
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